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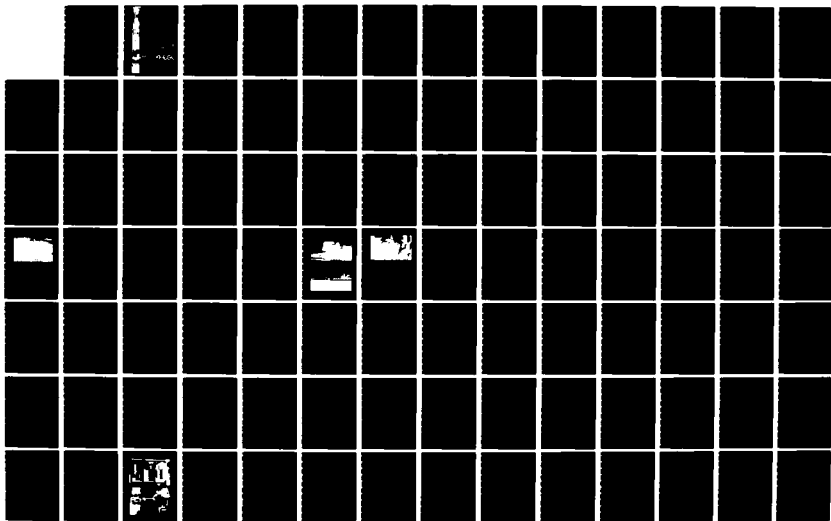
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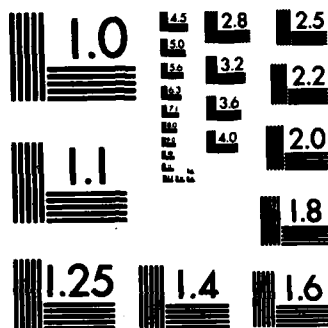
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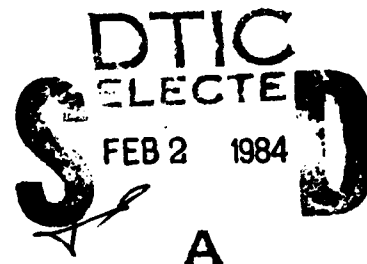
**DEVELOPMENT OF CRITERIA FOR THE
USE OF ASPHALT-RUBBER AS A STRESS-
ABSORBING MEMBRANE INTERLAYER (SAMI)**

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DECEMBER 1983

**FINAL REPORT
SEPTEMBER 1979 - JUNE 1983**



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<p>→ This report documents over 2 years of research efforts to characterize asphalt-rubber mixtures to be used in Stress-Absorbing Membrane Interlayers (SAMI). The purpose of these SAMIs is to retard or prevent reflection cracking in asphalt-concrete overlays. Several laboratory experiments and one field trial were conducted to define significant test methods and parameters for incorporation into construction design and specification documents.</p>		

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20. ABSTRACT (Concluded)

Test methods used in this study included a modified softening point test, force-ductility, and Schweyer viscosity. Variables investigated included

- (1) Laboratory-mixing temperature
- (2) Rubber type
- (3) Laboratory storage time
- (4) Laboratory storage condition
- (5) Laboratory batch replication
- (6) Laboratory mixing time
- (7) Field mixing time
- (8) Laboratory test temperature
- (9) Force-Ductility elongation rates
- (10) Asphalt grade

It was found that mixing temperature, mixing time, rubber type, and asphalt grade all have significant effects upon the behavior of asphalt-rubber mixtures. Significant variability was also noticed in different laboratory batch replications. Varying laboratory test temperature and force-ductility elongation rate revealed further differences in asphalt-rubber mixtures.

Guide specifications are proposed based upon the materials which were used in this study. Conclusions are made regarding the data collected in this investigation and recommendations are made for the conduct of further research. It should be noted that new materials are being developed using asphalt and rubber which have properties different from the materials investigated in this study. The development of these materials should not be discouraged by strict adherence to the findings published here.



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PREFACE

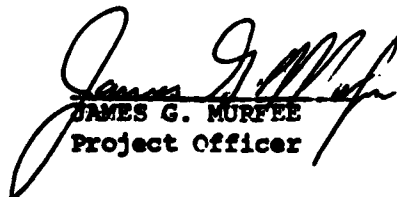
This report was prepared by the New Mexico Engineering Research Institute (NMERI), University of New Mexico, at the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico, under Contract F29601-81-C-0013, Job Order 20544P29, for the Engineering and Services Laboratory, Headquarters Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

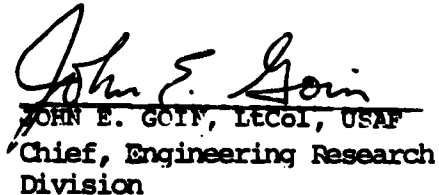
This report summarizes work done between September 1979 through June 1983. Mr. James G. Murfee was the AFESC/RDCF Project Officer.

The authors recognize the efforts of the previous principal investigators Dale S. Decker and T. Scott Shuler. Mr. Shuler is to be further credited with the development of the modified softening point test. NMERI engineers who contributed to testing and data interpretation in this project include Debora J. Hamberg, Lary R. Lenke, Badru M. Kiggundu, and Richard Graul. Assistance in chemistry was provided by Betty Nusser. Special acknowledgment is due to the project technicians, particularly Ginger L. Kiscaden, who contributed to the study--Thomas Escobedo, Brenda M. Wiuff, Thomas M. Trujillo, and Robert P. McNeill. Credit is also due Robert L. Dunning, Project Consultant, for his guidance in data interpretation and specifications development. Gene Morris of Western Technologies, Inc., Peggy Simpson of Sahuaro Asphalt and Petroleum Co., and Bob Smythe and Jim Chehovits of International Surfacing, Inc. also helped develop specifications. The authors also extend appreciation to Carolyn Lara, Karen Pilant, and Herminia Hemmet for their administrative assistance.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.


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Project Officer


JOHN E. GOIN, LTCOL, USAF
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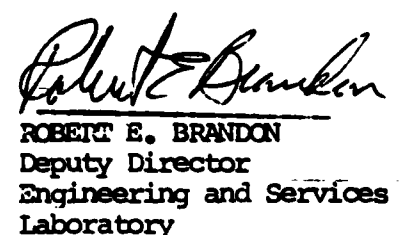

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SECTION I

INTRODUCTION

BACKGROUND

The idea of using a combination of asphalt and rubber in pavement construction is not a recent innovation. Samuel J. Whiting was awarded a U. S. patent in 1873 for an asphalt paving mixture containing 1 percent balata. A German patent was issued to Charles de Caudenberg of Nice, France in 1899 for rubberizing pavement. The earliest documented asphalt-rubber pavement construction took place in Cannes, France in 1902 (Reference 1). Since these early experiences with asphalt and rubber combinations, numerous patents have been issued for various applications of asphalt-rubber (Reference 2).

An asphalt-rubber seal coat was developed by Charles H. McDonald while he was Engineering Supervisor for Phoenix, Arizona (Reference 3). This product was successful in providing a durable wearing surface for pavements with severe alligator cracking. Further research with this process revealed that there was promise in using the material as an interlayer to prevent the reflection of cracks from an old pavement to a new asphalt concrete overlay (Reference 4). The asphalt-rubber seal coat concept is commonly referred to as a stress-absorbing membrane (SAM) and the interlayer concept is called a stress-absorbing membrane interlayer (SAMI).

McDonald's method involved combining up to 33 percent ground, reclaimed tire rubber in asphalt to absorb direct tensile, flexural, and shearing stresses (Reference 4). Since McDonald developed the material in the mid-1960s, a number of studies have been conducted on construction procedures and field performance (References 4 through 8) as well as laboratory evaluations (References 3 and 9 through 20). Efforts have also been made to relate asphalt-rubber properties to the reduction of crack propagation in pavement systems (References 5, 12, and 21).

Recognizing the potential benefits of asphalt-rubber mixtures in pavement systems, the Air Force Engineering and Services Center (AFESC) decided to initiate a technology review of the material in April 1977 (Reference 22).

Two of the conclusions made in this study were (1) that asphalt-rubber mixtures seem promising in the prevention of reflection cracking, and (2) that asphalt-rubber interlayers should be investigated in conjunction with conventional asphalt concrete overlays. The AFESC decided to fund a subsequent investigation on asphalt-rubber SAMIs. The results of this investigation are the subject of this report.

OBJECTIVE

The objective of this study was the evaluation of asphalt-rubber mixtures for use in the design, construction, and maintenance of airfield pavements to prevent or retard the development of fatigue and reflective cracking in these pavements and thereby extend their service life.

SCOPE

This research effort was intended to develop technical guidance for the use of asphalt-rubber as a stress-absorbing membrane interlayer for airfield pavements. The work in this project included:

1. The evaluation of asphalt-rubber component materials.
2. The development of recommended procedures for the production and application of asphalt-rubber mixtures.
3. The development of criteria for the use of asphalt-rubber mixtures as a SAMI for airfield pavements.

CONDUCT OF RESEARCH

This research was composed of several experiments divided into three distinct phases. The first phase had two experiments which investigated three combinations of rubber type and asphalt grade. The following variables were used in the first experiment:

1. Laboratory mixing temperature

2. Laboratory storage period
3. Laboratory storage condition

The second experiment used the same asphalt-rubber combinations and these variables:

1. Laboratory mixing time
2. Laboratory mixing replication

The second phase of this study was the construction and evaluation of an asphalt-rubber SAMI field trial. The same combinations of rubber type and asphalt grade used in the first phase were used as interlayers on an airfield parking apron. Different field mixing times were used in the construction. Samples were taken during construction and evaluated in the laboratory at time intervals up to 6 months. This was done to ascertain the effects of diluent added to the field trial material.

In the third phase, laboratory-prepared materials were tested under different temperatures and loading rates. This was done to ascertain the applicability of viscoelastic time-temperature principles. Evaluating stress-strain characteristics of the material may eventually lead to performance criteria which can be used in construction specifications. This portion of the research included three asphalt grades as well as the three rubber types used in the first two phases.

Factors which were not evaluated in this study include different gradations of rubber, different crude sources of asphalt, the effects of asphalt modifiers, and the effects of diluent in laboratory mixtures.

SECTION II

MATERIALS AND TESTING

MATERIALS

The asphalts and rubbers used in this project were commercially available products. Three grades of asphalt and three rubber types were evaluated. A diluent was employed in the field trial at Kirtland AFB. The interactions of these materials are important in determining the characteristics of the final asphalt-rubber product. Therefore the characteristics of these materials, by themselves, are presented here.

Asphalts

Table 1 lists the properties of the asphalts which were utilized in this study. The three grades were AC-5, AC-10, and AC-20. The AC-5 came from a Wyoming crude whereas the AC-10 and AC-20 were West Texas products from the Permian basin. The AC-10 and the AC-5 did not meet the American Society for Testing and Materials (ASTM) specification D 3381 for viscosity at 140°F (Reference 23). Note that the AC-5 had a higher percentage of aromatics than did the other two asphalts. This characteristic is important because it is suspected that the aromatic fraction is the most likely fraction to be absorbed by the rubber (Reference 3). If this is true then asphalts containing low percentages of aromatics could become embrittled when mixed with rubber.

The AC-20 asphalt was used throughout the study. It was the only asphalt used in the investigation of laboratory variables and in the construction of the field trial. All three asphalts were used in the temperature and time effects studies.

Rubbers

The rubbers used in this research had very similar gradations as shown in Table 2. However, the rubbers differed in the methods used to produce them from reclaimed tires as well as the parts of the tires. TP044 is an ambiently ground rubber from automobile tire treads. The whole tire carcass is used in the production of C-104 which is also produced under ambient conditions. APC-10 is a cryogenically produced whole tire rubber. The properties of these rubbers are listed in Table 3.

TABLE 1. PROPERTIES OF ASPHALTS USED IN THIS STUDY

Asphalt	Crude Source	Specific gravity at 77°F	Penetration at 77°F, 5 s, 100 g, 0.1 mm	Viscosity at 140°F, p	Viscosity at 275°F, cSt	Ring and Ball Softening Point, °F	Clay-Gel Asphaltenes, %	Compositional Analysis Polars, %	Aromatics, %	Saturates, %
AC-5	Wyoming	1.024	160	622	224	104	20.62	41.70	24.01	13.67
AC-10	West Texas	1.003	90	1394	318	114	21.79	40.40	15.10	22.71
AC-20	West Texas	1.007	72	1945	355	120	21.42	37.90	18.11	22.57

TABLE 2. GRADATION OF RUBBER PARTICLES FOR
RUBBER TYPES USED IN THIS STUDY

Sieve Size	TP044 percent passing	C-104 percent passing	APC-10 percent passing
No. 4	100	100	100
No. 8	100	100	100
No. 10	100	99	100
No. 16	87	52	59
No. 20	32	29	31
No. 30	2	14	13
No. 40	1	8	7
No. 50	0	4	3
No. 100	0	1	1
No. 200	0	0	0

TABLE 3. PROPERTIES OF RECLAIMED RUBBER USED IN THIS STUDY

Rubber Type	Source	Production Conditions	Acetone Extract, %	Ash Content, %	Specific Gravity
TP044	Auto tire tread	Ambient	16.4	6.4	1.149
C-104	Whole tire	Ambient	14.6	6.9	1.154
APC-10	Whole tire	Cryogenic	19.3	3.5	1.145

TESTING

Modified Softening Point Temperature

This test is a variation of the ring and ball softening point test described by ASTM D 36 (Reference 23). The modified softening point test combines this procedure with an idea proposed by Krchma in 1967 (Reference 24). The specimen geometry for this test is a 1-inch by 3/8-inch cylinder of asphalt-rubber with steel balls fixed at both ends.

The testing medium used for the modified softening point test is an ethylene glycol bath. The sample is held vertically in the bath by attaching one of the balls to a magnet and allowing the other end of the sample to be freely suspended. The bath temperature is raised at a constant rate until the test is completed. The temperature in the bath is recorded at the time the specimen extends 1 inch. This is referred to as the modified softening point temperature. The method and apparatus are described in detail in Appendix A.

This test is relatively simple and requires no large investment in equipment. Initial experimentation in this study revealed that asphalt-rubber would tear and the ball would fall through the material in the standard ring and ball configuration. In the modified test, the bottom ball remains attached to the material throughout the test.

Constant Pressure (Schweyer) Viscosity

The Schweyer rheometer is a constant stress viscometer as discussed in References 25 and 26. The device has been used primarily to characterize asphalt cements. However, Jimenez found the Schweyer rheometer useful for measuring the flow properties of asphalt-rubber (Reference 13). Certain modifications had to be made so that the size of the rubber particles did not influence the measurement of viscosity for the whole asphalt-rubber system. Many of these modifications were included in this study. These modifications are discussed in detail in Appendix A.

Data obtained from the Schwyer rheometer can be used to determine a unique relationship between shear stress and shear rate at a given test temperature. This relationship is

$$\tau = a\dot{\gamma}^c \quad (1)$$

where

τ = shear stress

a = statistical regression coefficient

$\dot{\gamma}$ = shear rate

c = statistical regression coefficient

A c -value of 1 indicates that the material is a Newtonian fluid. Materials of pseudoplastic nature have a c -value of less than 1. A dilatent material would have a c -value greater than 1. The constant " a " represents a complex viscosity corresponding to a shear rate of 1.0 s^{-1} .

The apparent viscosity is determined by taking the derivative of Equation (1):

$$\eta_a = \frac{d\tau}{d\dot{\gamma}} = a\dot{\gamma}^{c-1} \quad (2)$$

or

$$\eta_a = a\dot{\gamma}^b \quad (3)$$

where

η_a = apparent viscosity

$b = c - 1$

The derivative represents the slope between the origin of a τ versus $\dot{\gamma}$ plot and any other point on the function τ versus $\dot{\gamma}$. It is analogous to a secant modulus.

Equation (3) is used to calculate the apparent viscosity at a given shear rate. If τ is measured in pascals (Pa) and $\dot{\gamma}$ in s^{-1} , then " a " has units of $\text{Pa} \cdot \text{s}$, " b " and " c " are dimensionless, and η_a has units of $\text{Pa} \cdot \text{s}$. One $\text{Pa} \cdot \text{s}$ represents a viscosity value and corresponds to 10 poises.

Comparison of Schwyer viscosity can be made between different materials using a technique which evaluates the viscosity at a constant power of 100 W/m³. This is accomplished by determining the shear rate at which Equation (1) intersects the following equation:

$$\tau \cdot \dot{\gamma} = 100 \text{ Pa} \cdot \text{s}^{-1} = 100 \text{ W/m}^3 \quad (4)$$

Solving for τ in terms of $\dot{\gamma}$ from Equation 4 with subsequent substitution into Equation (1) yields a value of $\dot{\gamma}$ at which Equations (1) and (4) intersect. The viscosity at a constant power of 100 W/m³ is computed thusly:

$$\eta_{100} = a \frac{100}{a} \frac{c-1}{c+1} \quad (5)$$

For the materials used in this study viscosities at 0.05 s⁻¹ shear rate and constant power of 100 W/m³ are reported as well as c-values.

Force-Ductility

This test uses a modified ASTM D 113 device (Reference 23) to measure tensile properties. A force transducer is inserted in the ductility train in much the same way as described by Anderson and Wiley (Reference 27). In this study, three load cells were fixed to one end of a standard ductility testing machine. Early work by Pavlovich et al. (Reference 28) showed promise for this test in asphalt-rubber research. The apparatus used in this study was based on Pavlovich's work and was further modified.

The standard ductility mold is modified so that a 0.16-in.² cross section is maintained throughout the sample length. Sample deformation is measured by placing gage marks at the ends of the sample length and measuring the displacement at specified intervals during the test. Load cells monitor the force throughout the test. A strip chart recorder produced a load-deformation curve. Appendix A gives a detailed description of this test.

Values reported here include maximum true stress, true strain at maximum, true stress, compliance, and work. True stress was calculated according to the following formula:

$$\sigma = \frac{P}{A_0} \left[1 + \frac{\Delta L}{L} (C_1) \right] \quad (6)$$

where

σ' = true stress

P = load

A_0 = original cross-sectional area = 0.16 in.²

ΔL = change in length as measured on the time axis of the load-elongation curve

L = initial gage length

C_1 = constant to account for actual sample deformation

The equation for true strain was

$$\epsilon' = \ln \left[1 + \frac{\Delta L}{L} (C_1) \right] \quad (7)$$

where

ϵ' = true strain

The relationship between stress and strain was expressed as the compliance. Compliance changes during the test. Therefore compliance was calculated for the relatively flat portion of the load-deformation curve. The equation for compliance was

$$D(t) = \frac{\epsilon'(t)}{\sigma'(t)} \quad (8)$$

where $D(t)$ = compliance at any point in time.

Work was computed by calculating the area under the load-elongation curve. This is sometimes called toughness and it is the total energy required to fracture the test specimen.

SECTION III

LABORATORY INVESTIGATION OF VARIABLES

Initially, two laboratory experiments were performed in this project. They were designated as Matrix I and Matrix II. Both were full-factorial designed experiments. The variables in Matrix I included

1. Rubber type--3 levels
2. Mixing temperature--3 levels
3. Laboratory storage time--3 levels
4. Laboratory storage condition--3 levels

The mixing time, asphalt grade, rubber gradation, asphalt source, and asphalt-to-rubber ratio were held constant in Matrix I.

Matrix II had the following variables:

1. Rubber type-3 levels
2. Mixing time--3 levels
3. Batch repetition--2 levels

In this experiment the asphalt grade, rubber gradation, asphalt source, and asphalt-to-rubber ratio were held constant as in Matrix I. However, the mixing temperature was also held constant in Matrix II.

As stated in Section II, the dependent variables were the modified softening-point test, Schwyer viscosity, and force-ductility. In Matrix I and Matrix II the Schwyer viscosity was measured at 60°F only, and the force-ductility was run at 39.2°F only. Time and temperature effects are discussed in Section V.

MATRIX I

Variables

The first experiment investigated both laboratory and production variables. The production variables were the rubber types, described in Section II, and mixing temperatures of 325°, 375°, and 425°F. The laboratory

variables were storage periods (1, 8, and 28 days) and storage conditions (frozen and ambient). The mixing time in this experiment was held constant at 1 hour.

The purpose in choosing these independent variables was to investigate their influences upon asphalt-rubber properties. The production variables were chosen so that a range of available reclaimed rubbers was tested along with a range of possible mixing temperatures. The laboratory variables represent conditions which might influence testing results.

Results

The data were analyzed by conventional multiple analysis of variance, the Duncan multiple-range test, and student tests when appropriate. The results of Matrix I are found in Tables B-1 and B-2, in Appendix B.

The modified softening point results showed significant differences in the rubber types and mixing temperatures at an alpha level of 0.05. However, no significant differences were detected due to the storage periods or storage conditions at the same alpha level. Figure 1 illustrates how the modified softening point temperatures of the mixtures changed with the mixing temperatures. All three rubbers seemed to achieve a peak softening point temperature at the 375°F mixing temperature. The TP044 mixture showed the greatest change with mixing temperature from the lowest softening point temperature of 139°F at the 325°F mixing temperature to 150°F at the 375°F mixing temperature.

Figure 2 shows that viscosity at a constant 100 W/m³ and 60°F demonstrates the same trend as the modified softening point with respect to mixing temperatures. A peak value appears for the 375°F mixing temperature. Viscosity values ranged from about 1.5×10^9 to 1.7×10^9 poises at the 325° mixing temperature. At the 375°F mixing temperature, viscosity at constant power ranged from about 1.95×10^9 to about 2.15×10^9 poises. The mixture containing cryogenically produced rubber had the highest viscosities at all the mixing temperatures.

The APC-10 mixture also had the highest viscosities at 0.05 s⁻¹ shear

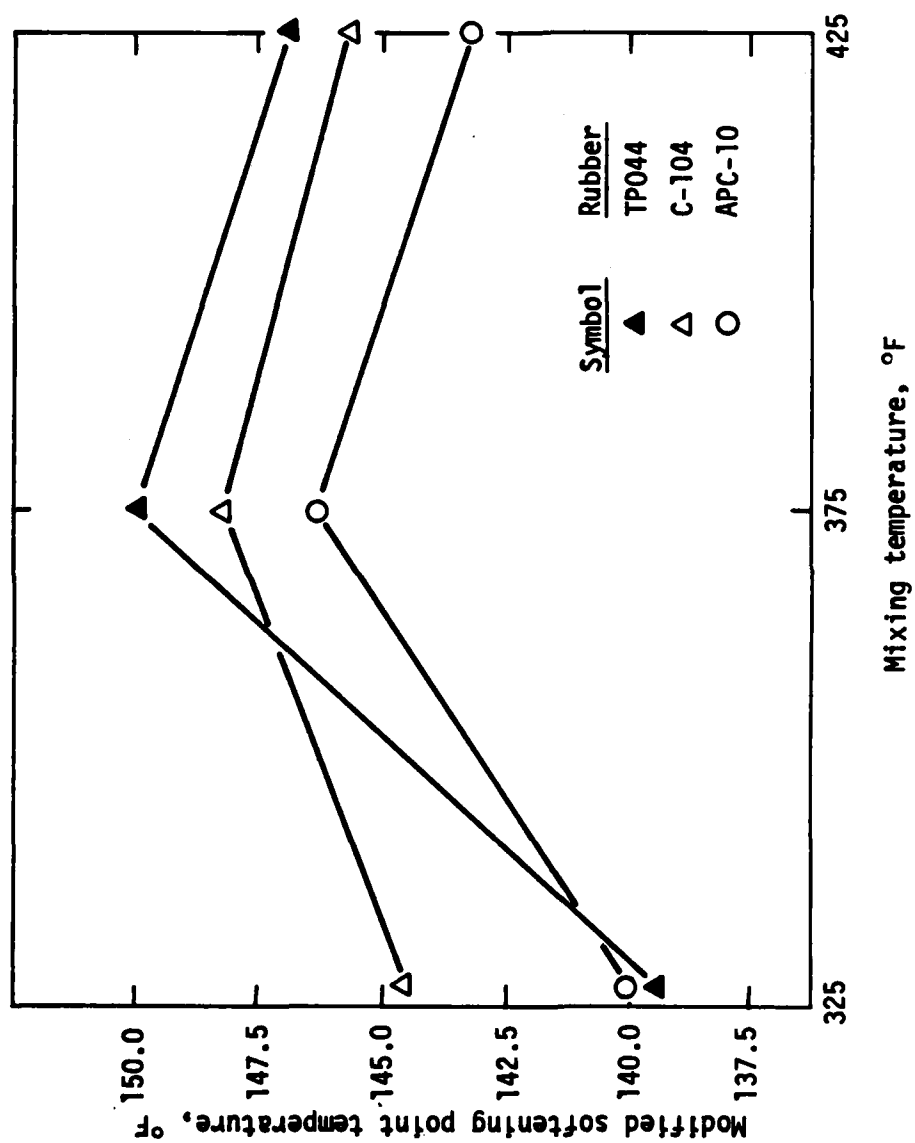


Figure 1. Effect of Mixing Temperature on Modified Softening Point Temperature.

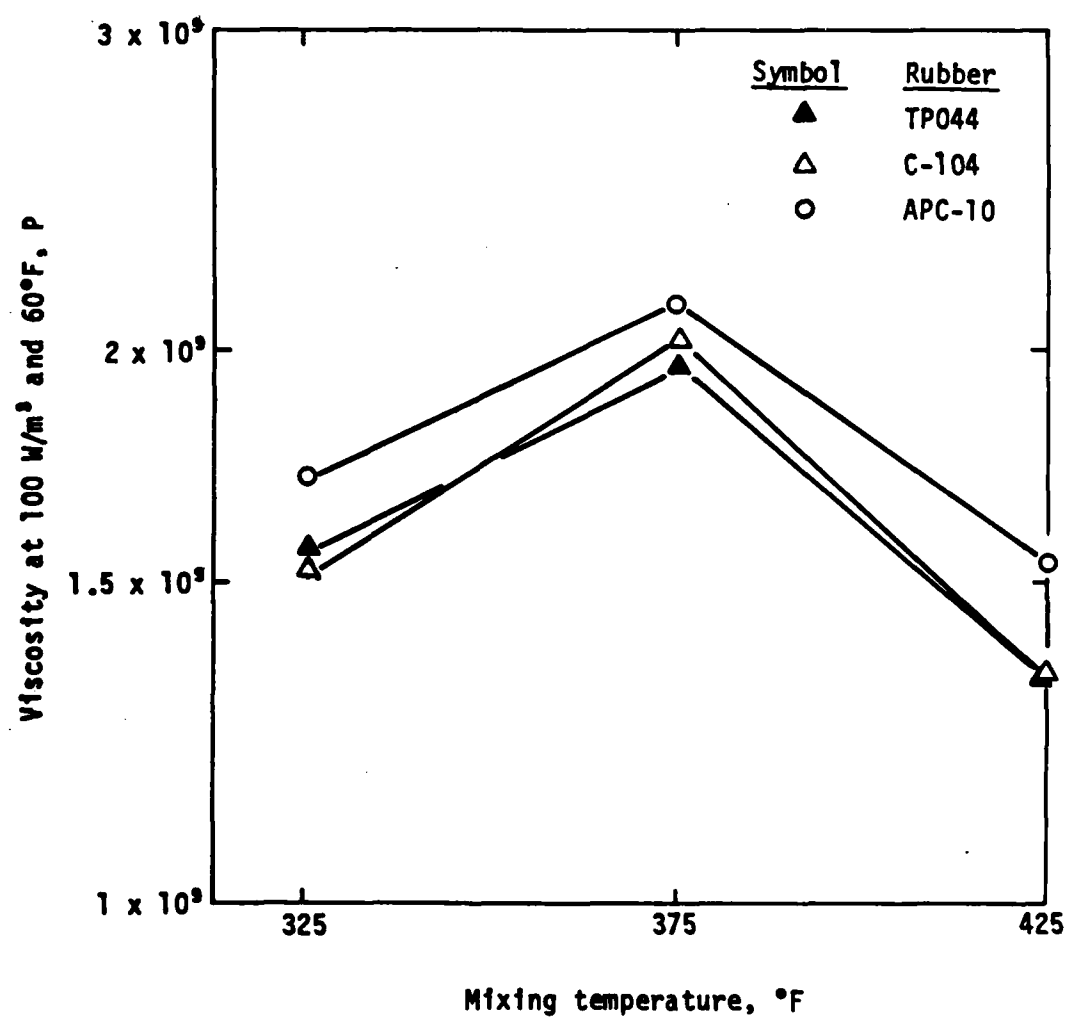


Figure 2. Effect of Mixing Temperature on Viscosity at 100 W/m² and 60°F.

rate at all the mixing temperatures as shown in Figure 3. Only the C-104 mixtures showed a peak value in this viscosity measurement. All the mixtures decreased in viscosity at 0.05 s^{-1} at the 425°F mixing temperature. Viscosity values ranged from approximately 1.0×10^8 poises for the TP044, 425°F mixture to about 1.9×10^8 poises for the APC-10, 325° and 375°F mixtures.

Storage condition showed no effects upon viscosity values up to 28 days. Storage period showed significant effects upon viscosity values at the 28-day level. These effects are suspected to be due to test variability rather than the storage period.

Figure 4 shows the effect of mixing temperatures on the maximum true stress of the asphalt-rubber mixtures at 39.2°F . The TP044 mixtures maintained the highest maximum stress values at all three mixing temperatures. The values converge at the 375°F mixing temperature and diverge at the 425°F mixing temperature. Figure 5 shows that the true strain at maximum true stress increases with increasing mixing temperature. Mixtures made with APC-10 consistently had the lowest strains while the TP044 mixtures consistently had the highest strains. These strain values ranged from 0.93 in./in. for APC-10 at the 325°F mixing temperature to 1.49 in./in. for TP044 at the 425°F mixing temperature.

Compliance increased with mixing temperatures as shown in Figure 6. The APC-10 mixture consistently exhibited the lowest compliance values, ranging from $39 \times 10^{-4} \text{ psi}^{-1}$ at the 325°F mixing temperature to $60 \times 10^{-4} \text{ psi}$ at the 425°F mixing temperature. The TP044 and C-104 mixtures were relatively close in compliance at all the mixing temperatures. These two mixtures had values ranging from approximately $48 \times 10^{-4} \text{ psi}^{-1}$ at the 325°F mixing temperature to $72 \times 10^{-4} \text{ psi}^{-1}$ at the 425°F mixing temperature.

The data presented show that asphalt-rubber mixtures are very sensitive to the temperatures at which they are prepared.

Storage condition and storage period showed minimal effects upon the test results for Matrix I.

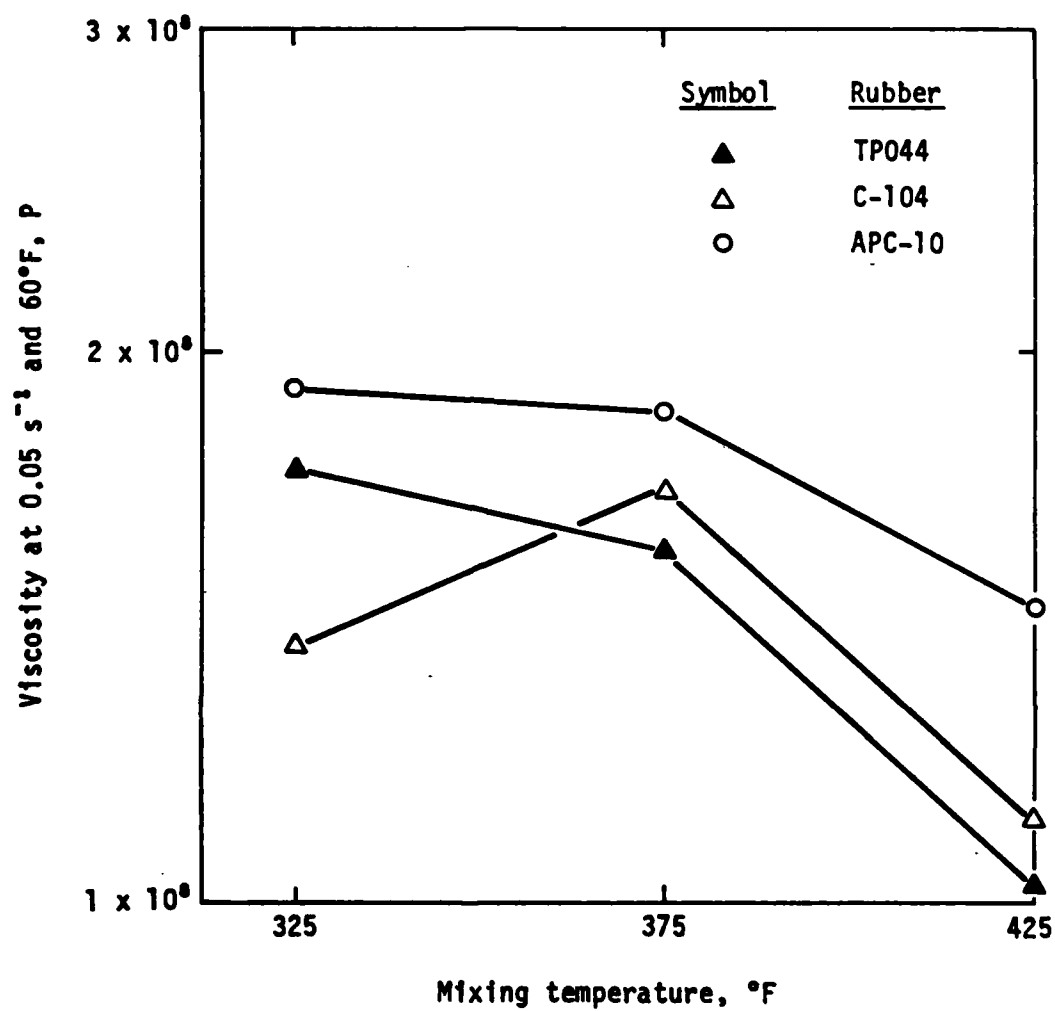


Figure 3. Effect of Mixing Temperature on Viscosity at 0.05 s^{-1} Shear Rate and 60°F .

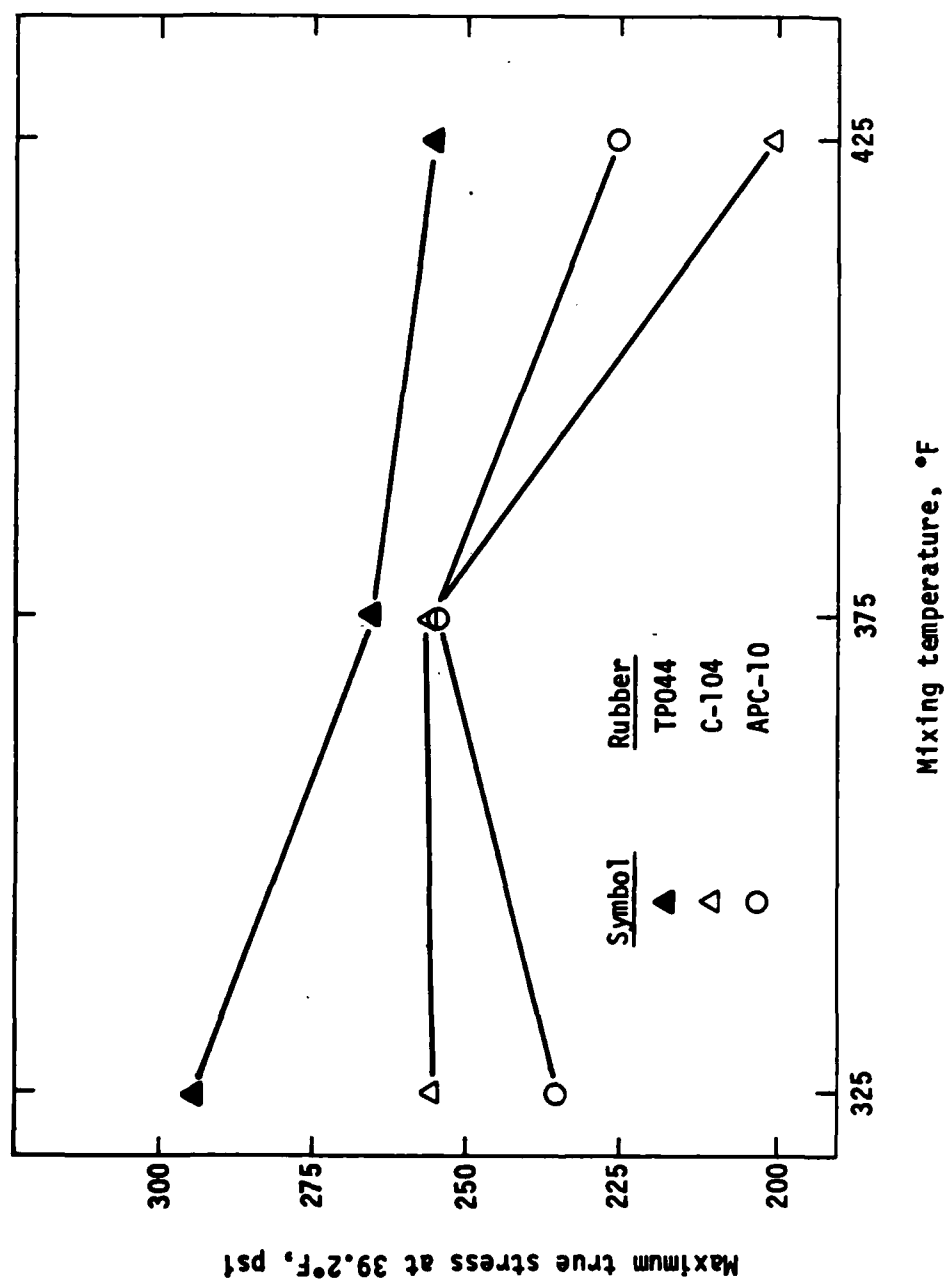


Figure 4. Effect of Mixing Temperature on Maximum True Stress.

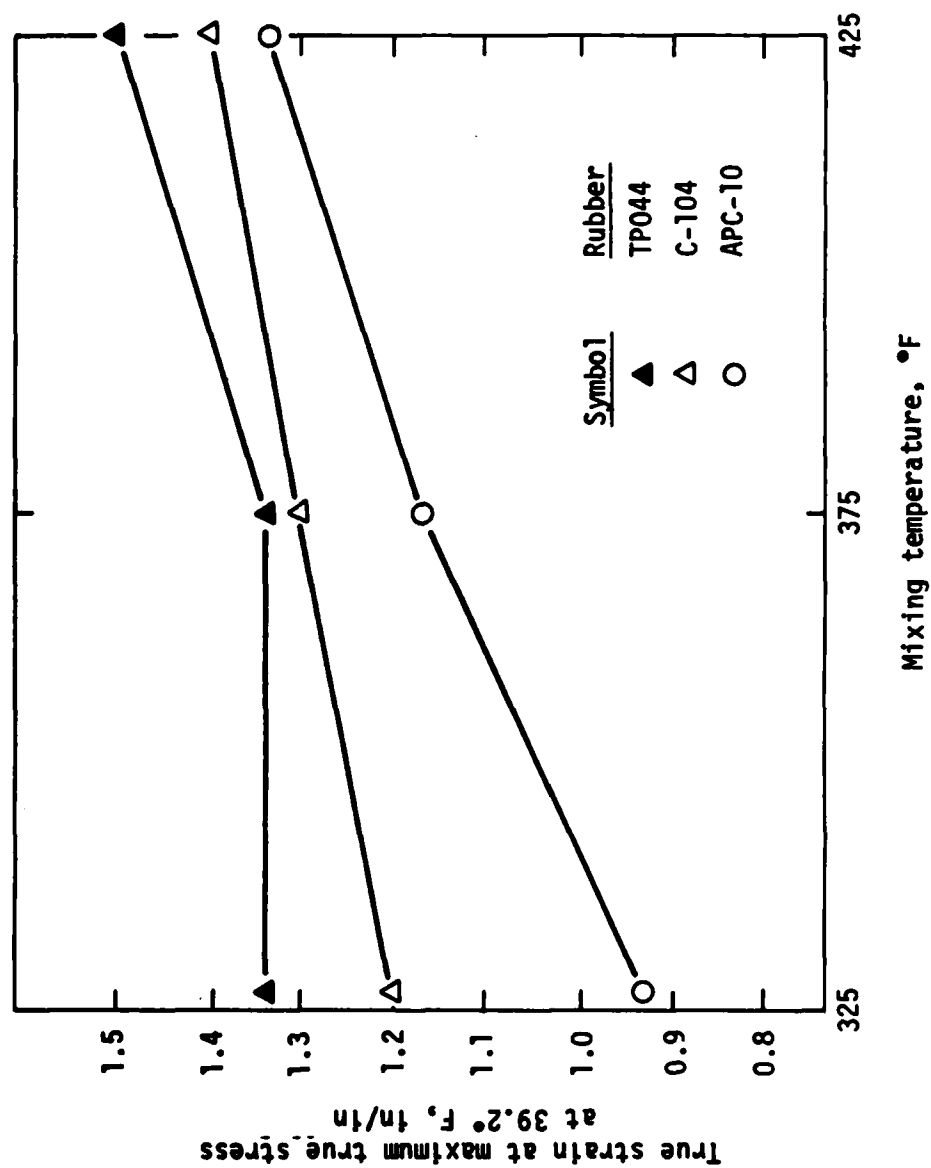


Figure 5. Effect of Mixing Temperature on True Strain at Maximum True Stress.

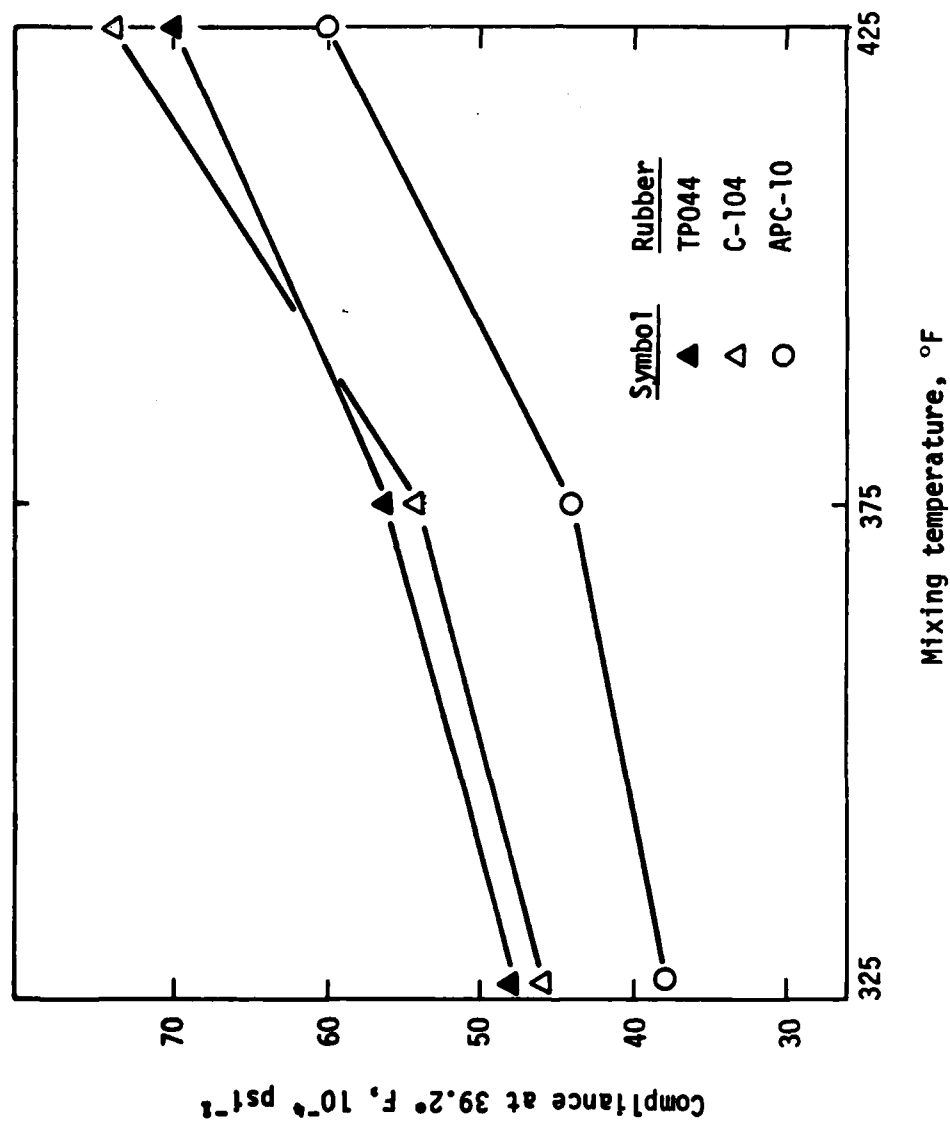


Figure 6. Effect of Mixing Temperature on Compliance.

MATRIX II

Variables

In the second laboratory experiment two production variables and one laboratory variable were investigated. The production variables included mixing time (0.5, 1.0, and 4.0 hours) and rubber type as discussed in Section II. The laboratory variable of interest was the batch-to-batch replication. All the mixtures in this experiment were prepared at 375°F.

By choosing the three mixing times it was hoped that it would be possible to determine the effects of holding the material in a field distributor truck over a range of times. The laboratory batch-to-batch replication was of interest because the repeatability of the mixing procedure was unknown.

Results

As with the previous experiment, the data were analyzed through the use of statistical methods. Tables B-3 and B-4 in Appendix B summarize the results of Matrix II.

Figure 7 illustrates the effect of mixing time on the modified softening point values for the various asphalt-rubber blends. The TP044 and APC-10 blends both exhibited a substantial initial increase in softening point temperatures while the C-104 mixture showed a slight decrease between the 0.5-hour and 1.0-hour mixing times. The differences in the softening point values decreased after 4 hours of mixing to between 151°F for C-104 and 154°F for TP044. Table B-4 shows the maximum standard deviation for one replication as 6.9°F and the minimum as 0.8°F.

The values of viscosity at 100 W/m³ after 4 hours of mixing at 375°F, as shown in Figure 8, are in the range 2.4×10^9 to 3.55×10^9 poises. All the values fell between 2×10^9 and 4×10^9 poises. No clear trends were observed for the three rubber types as were seen for the various mixing temperatures in Matrix I. Figure 9 shows how viscosity at the 0.05 s⁻¹ shear rate changed with the mixing time. Again, there are no clear trends. However, the APC-10 mixture consistently had a higher viscosity than the other two mixtures.

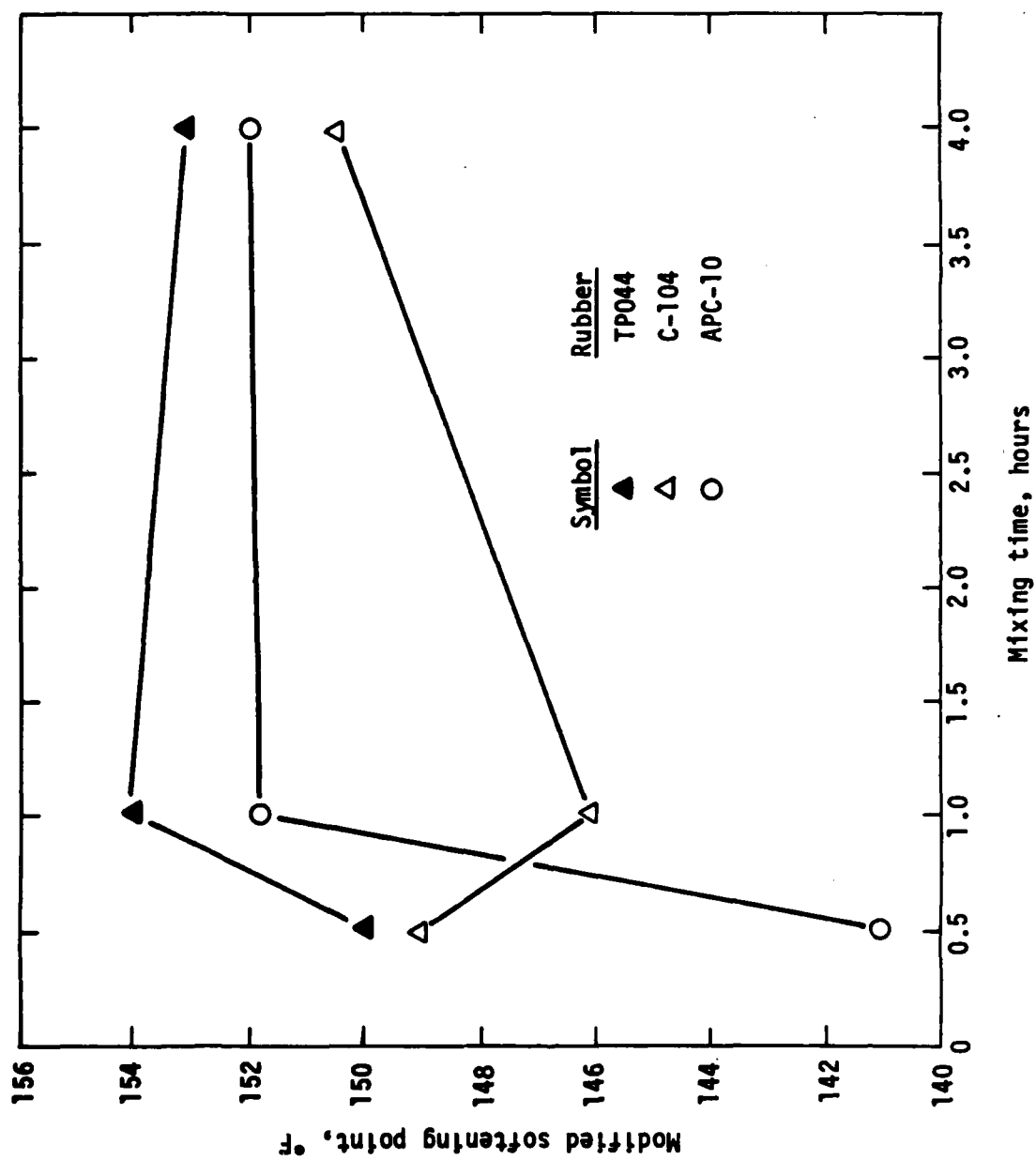


Figure 7. Effect of Mixing Time on Modified Softening Point.

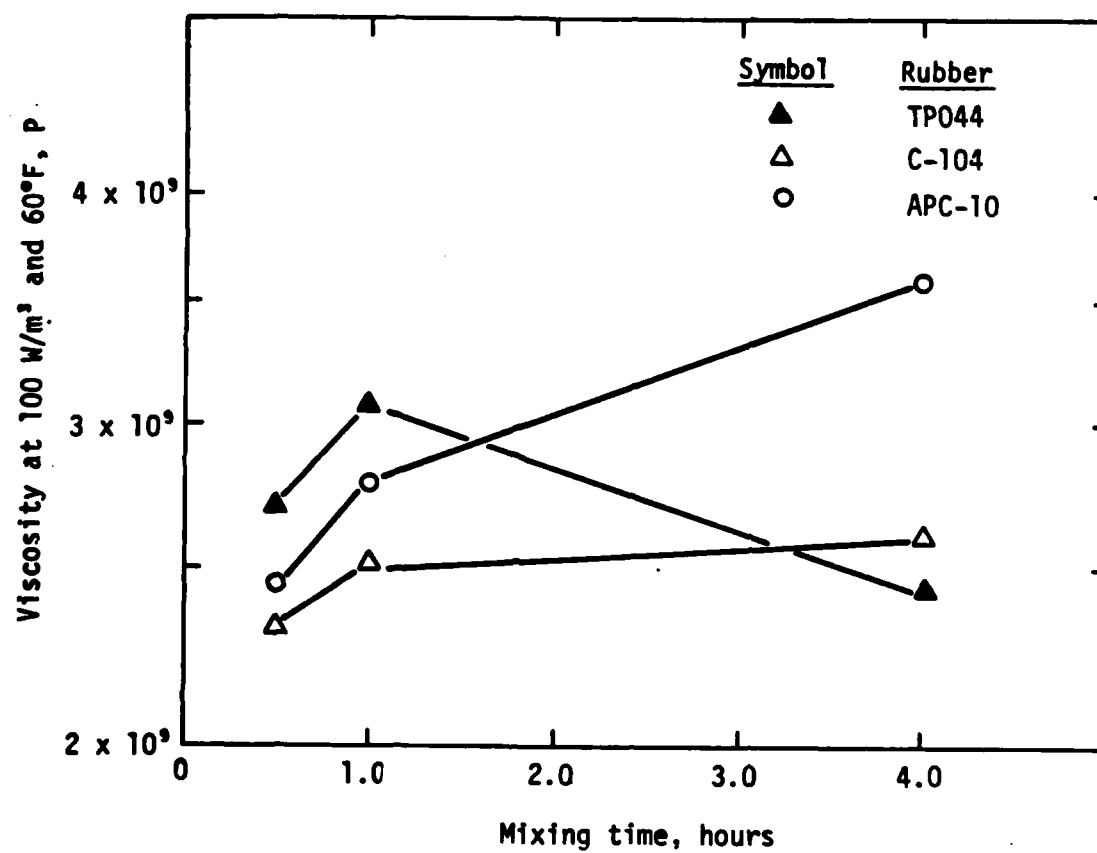


Figure 8. Effect of Mixing Time on Viscosity at 100 W/m³ and 60°F.

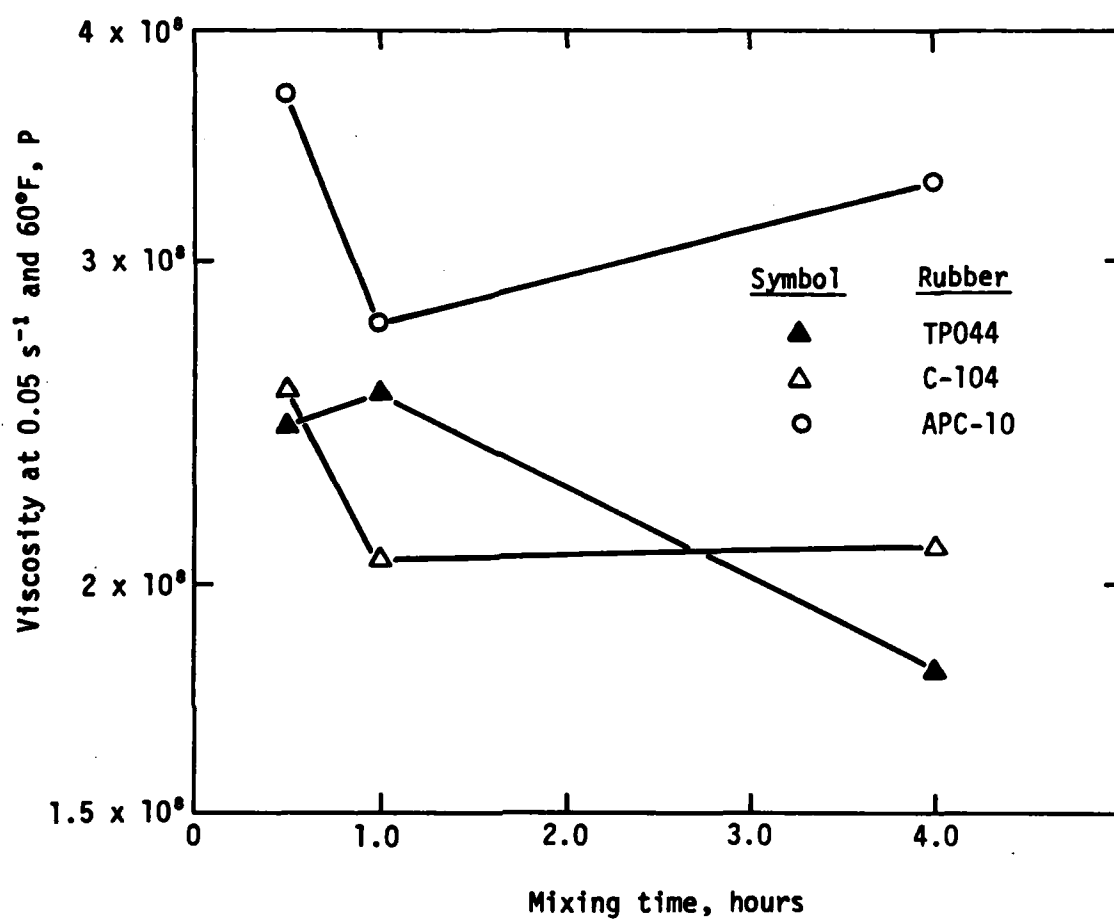


Figure 9. Effect of Mixing Time on Viscosity at 0.05 s^{-1} Shear Rate and 60°F .

The maximum true stress values shown in Figure 10 show no obvious trends with respect to mixing times. As with the softening point temperature, the maximum true stress value for APC-10 shows a great initial increase from 179 psi at the 0.5-hour mixing time to 220 psi at the 1-hour mixing time. The values of true strain at maximum true stress are shown in Figure 11. The effects of mixing time are more obvious here. For all three rubber types the strain values were greater at the 4-hour mixing time than at the 0.5-hour mixing time. The TP044 mixtures consistently had the highest true strains at maximum true stress, ranging from 1.22 in./in. at the 1-hour mixing time to 1.38 in./in. at the 4-hour mixing time. The APC-10 mixtures had the lowest true strain values from 0.81 in./in. at the 0.5-hour mixing time to 1.13 in./in. at the 4-hour mixing time.

The graph of compliance versus mixing time (Figure 12) clearly shows that compliance increases with mixing time for all three rubber types. As might be expected from the strain data, the APC-10 mixtures consistently had the lowest compliance values and the TP044 mixtures consistently had the highest compliance values. The APC-10 mixtures increased in compliance from $40 \times 10^{-4} \text{ psi}^{-1}$ at the 0.5-hour mixing time to $49 \times 10^{-4} \text{ psi}^{-1}$ at the 4-hour mixing time. Compliance values for the C-104 mixtures increased from 52 to $57 \times 10^{-4} \text{ psi}^{-1}$. Values for the TP044 mixtures ranged from $54 \times 10^{-4} \text{ psi}^{-1}$ at the 0.5-hour mixing time to $68 \times 10^{-4} \text{ psi}^{-1}$ at the 4-hour mixing time.

The batch-to-batch replications showed significant differences at the 0.05 alpha level for the values of work, maximum true stress, and true strain at maximum true stress. However, no significant differences between batch replications were detected for modified softening point values, viscosity at 0.05 s^{-1} shear rate, viscosity at 100 W/m^3 , or the values of compliance. This would indicate that the viscosity measurements were less sensitive to the batch replication than were the tensile measurements.

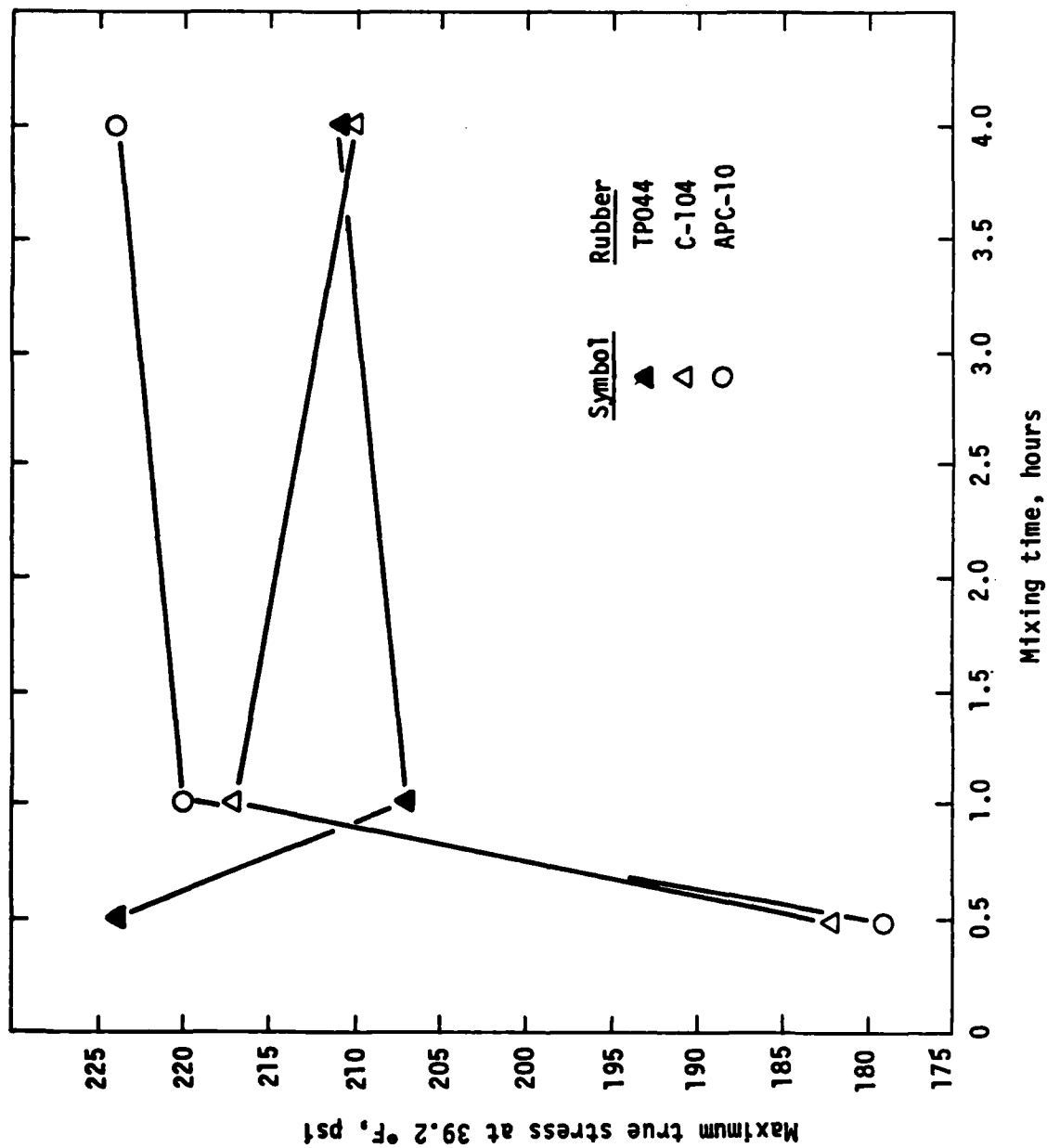


Figure 10. Effect of Mixing Time on Maximum True Stress.

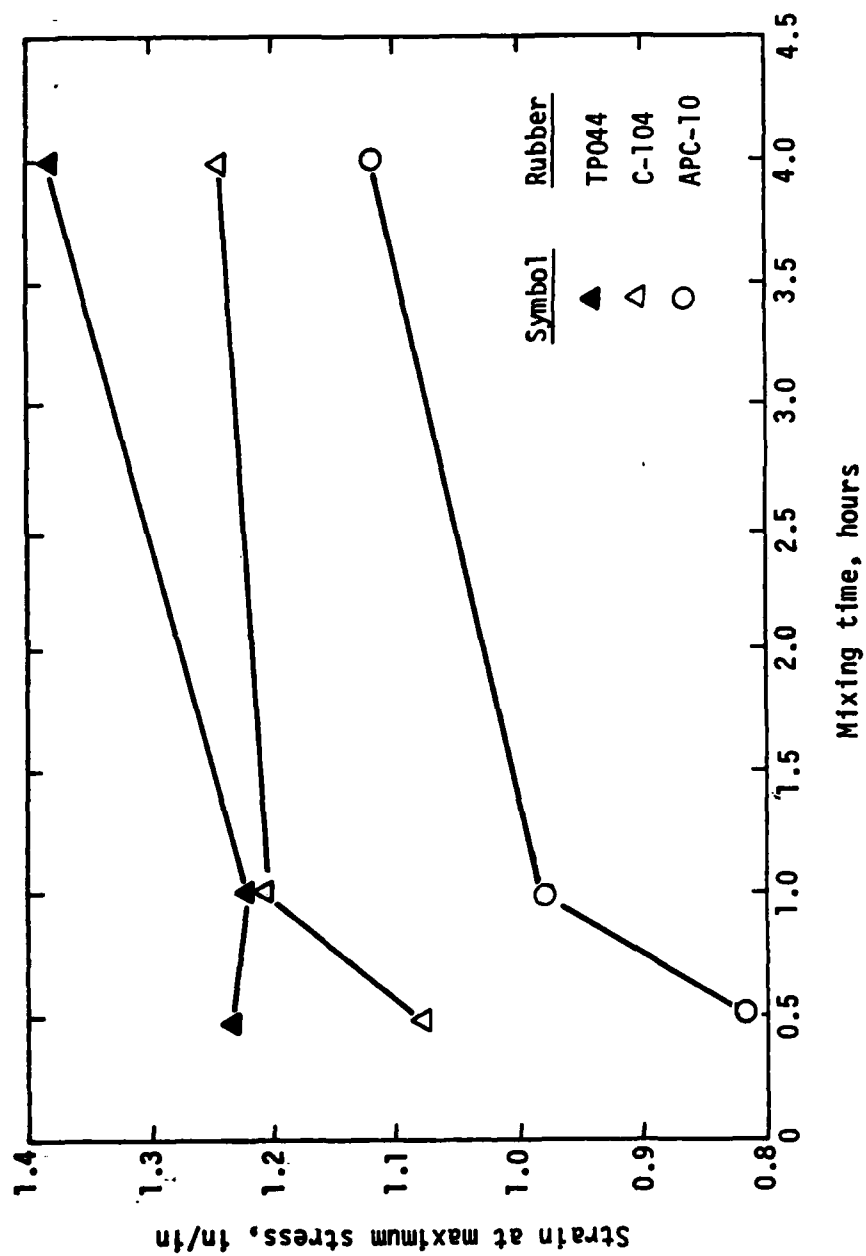


Figure 11. Effect of Mixing Time on True Strain at Maximum Stress.

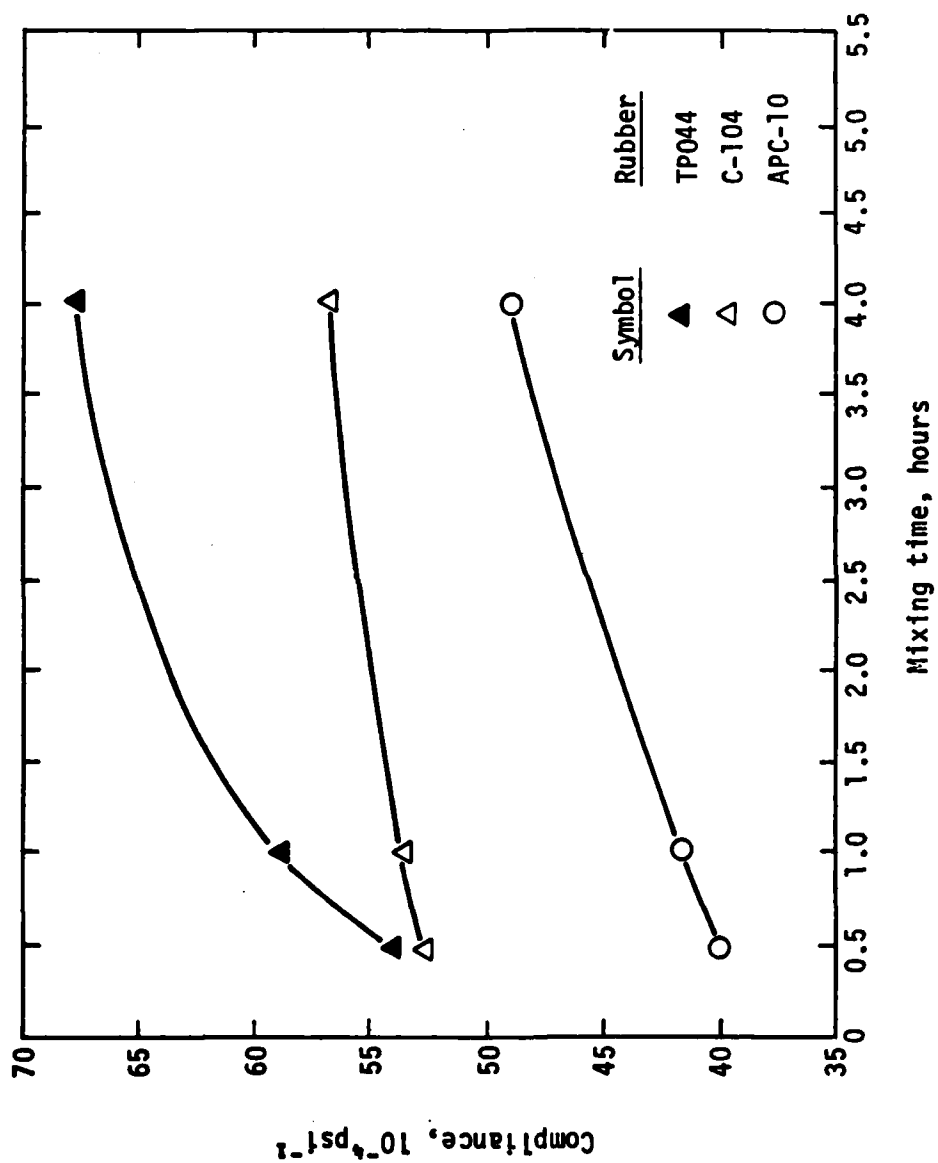


Figure 12. Effect of Mixing Time on Compliance.

SECTION IV

FIELD TRIAL

An asphalt-rubber SAMI field trial was constructed at Kirtland Air Force Base, New Mexico in November 1981. Variables which had been investigated in laboratory mixtures were applied to mixtures used in the field trial. These variables were three mixing times and three rubber types.

The field trial was constructed on Apron A. This airfield feature is 1900 feet long and 170 feet wide. The location of Apron A relative to other airfield features is shown in Figure 13.

PRECONSTRUCTION

Pavement Survey

When ideas were initially being considered for a pavement survey, it was thought that crack mapping would be the best method to keep track of reflective cracking. However, given the extent of the project and the frequency of the cracks, it was concluded that mapping would be extremely difficult. It was further decided that low-level aerial photography with high-resolution film would be the simplest and least expensive method to try. This technique worked well for the longer and wider cracks, but many smaller cracks in the pavement did not show up.

The magnitude of the crack-mapping problem may be deduced from a typical ground level photograph, Figure 14. It has since been decided that a better method of monitoring crack reflection is to wait for cracks to appear in the overlay. When the cracks appear, the frequency and locations are noted to determine if there is a correlation between the asphalt-rubber mixtures and cracking.

The types of cracking evident in the old pavement included block, longitudinal, and alligator. The pavement was in an advanced state of deterioration and a definite candidate for major rehabilitation.

Layout

Nine different asphalt-rubber mixtures were to be evaluated on two types of surface preparation. The rubber types used in the field trial were the same as those used throughout the research program as described in Section II.

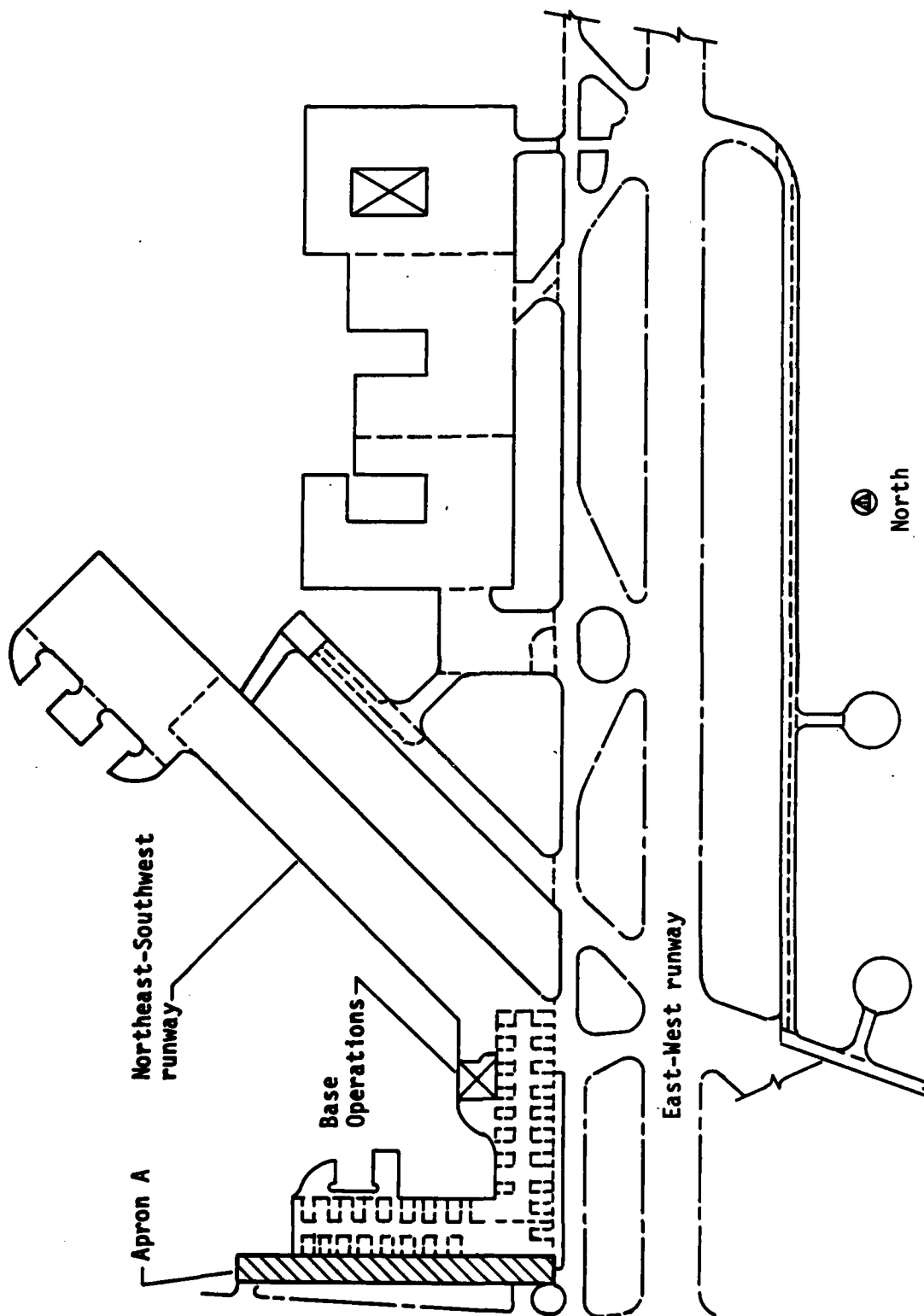


Figure 13. Location of Apron A Relative to Other Features at Kirtland AFB.



Figure 14. Apron A, Facing South at Station 11+00.

The designation for APC-10 was changed to CPR-10P for the field trial. The AC-20 used in the field trial came from the same source as the AC-20 used in the laboratory experiments. The three mixing times used in the field trials were 15, 60, and 160 minutes.

The two types of surface preparation consisted of a slurry seal placed directly on the aged pavement and heater scarification of the old pavement. On one of the control sections the old pavement was completely removed and a new 3-inch pavement was placed on the existing cement-treated base.

Figure 15 shows the layout of the field trial. The typical asphalt-rubber test section was 150 by 170 feet. In each test section only the western 20 feet were covered with the slurry seal prior to the asphalt-rubber application. The physical layout was accomplished by a survey crew. The sections were delineated by rubber type and mixing time.

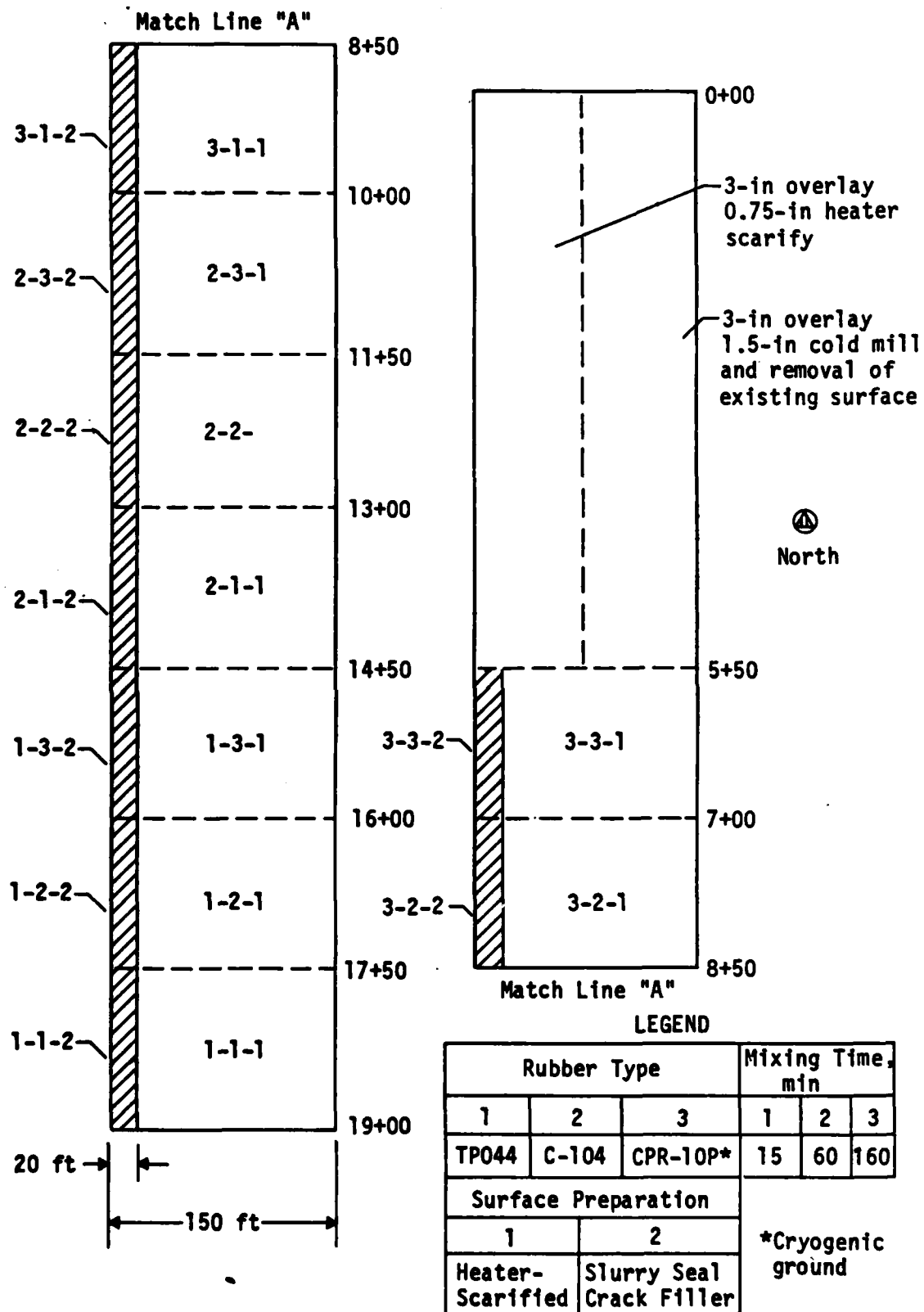


Figure 15. Layout of Apron A Test Sections.

CONSTRUCTION

Surface Preparation

The removal of pavement in the control section was accomplished by a tractor pulling a milling device which broke the pavement into approximately minus 1-inch size material. After milling, the material was windrowed and a front-end loader was used to place the material in dump trucks for disposal. This process was continued until the pavement had been removed to the level of the cement-treated base.

The heater scarification treatment of the old pavement was performed in both the control section and the test sections. In this process, tandem pavement heaters applied flames directly to the apron surface. Fuel was provided by propane tanks mounted in front of the heating units. A lot of smoke generated in the heating process was thought to be caused, to a large extent, by an old slurry seal on the apron. This slurry seal meant that there was an excess of asphalt on the pavement surface, closest to the heat. It was decided that the best way to approach this problem was to reduce the heat and move the heater units at a slower rate.

The heating process was followed by a 0.75-inch penetration of the scarifier teeth. Next, a paving screed was used to level the material which was followed by a pneumatic roller used for compaction. The benefits of heater scarification prior to the membrane application have been mentioned by Way (Reference 8) and Pickett and Lytton (Reference 29). Way suggests that this process rearranges the old asphalt concrete-crack pattern. This shortens the crack length and significantly reduces reflection cracking. Pickett states that energy required for crack propagation is sufficiently dissipated by the time the crack has emerged through a thin overlay of approximately the same thickness as heater scarification so that the membrane should prevent any further growth.

The slurry seal was applied to a 20-foot strip at the western edge of the apron. This was done mainly to accommodate concrete tiedowns in this part of the pavement as heater scarification would have been impractical. The slurry seal successfully filled the cracks while providing a thin overlay prior to the application of the asphalt-rubber membrane.

SAMI Placement

The laydown of the asphalt-rubber stress-absorbing membrane interlayer took place on 23 and 24 November 1981. Near ideal weather conditions prevailed during the asphalt-rubber application. The mean ambient temperature during construction hours was 68°F. The wind velocity was 8 miles per hour from the north and the relative humidity was 10 percent. All 15- and 60-minute mixtures were placed on November 23. All 160-minute mixtures were installed on November 24.

The equipment used in the construction of the membrane included

- three asphalt-rubber distributor trucks
- one asphalt-rubber mixer
- one kerosene tanker
- one chip spreader
- three dump trucks
- one steel-wheeled roller
- two pneumatic rollers
- one pavement sweeper

Materials incorporated in the SAMI test sections included

- three rubbers: TP044 (9840 pounds)
C-104 (8300 pounds)
CPR-10P (cryogenic) (9700 pounds)
- one asphalt cement: AC-20 from Chevron Oil Company,
Albuquerque (86,176 pounds)
- kerosene diluent (500 gallons)
- pea gravel (0.25 inches) (> 400 tons)

Sahuaro Asphalt and Petroleum Company of Phoenix, Arizona was the subcontractor hired to place the asphalt-rubber membrane. The mixing procedure used in the field trial was as follows:

1. The asphalt cement was heated to 420°F in a holding tank mounted on an asphalt-rubber mixer.

2. The rubber was poured into the mixer and the time was recorded at this point. The heated asphalt was slowly added to the rubber as the rubber was poured into the mixer. The time and mixture temperature were recorded after the final bag of rubber was added.

3. The asphalt and rubber were agitated in the mixer drum for about 15 minutes. This is considered to be approximately half the time required to combine the ingredients. The viscosity was measured using a hand-held rotational viscometer and was recorded with the temperature.

4. The asphalt-rubber was pumped into a spreader truck. The truck temperature, sample temperature, and viscosity were recorded at 15-minute intervals after this point.

5. The kerosene diluent was added to the mixture when the viscosity reached 8000 to 9000 centipoises. Usually 3 to 6 percent diluent is needed to achieve a spreadable consistency of 6500 centipoises or less. The countdown for the field trial mix times was begun at the beginning of the diluent addition.

The distributor trucks placing the asphalt-rubber traveled in the lateral direction across the apron. Figure 16 shows a distributor truck in operation.

A member of the paving crew rode on the rear of the truck to ensure that the spray bar did not become clogged. The chip-spreading operation immediately followed the distributor truck. The chip spreader was immediately followed by the steel wheel and pneumatic rollers, respectively, as shown in Figure 17. The chips were preheated but not precoated. The preheating and rolling combined to give good chip retention in the membrane. Next, a sweeper was used to remove excess aggregate from the SAMI surface. The completed SAMI is shown in Figure 18.

Overlay

Due to inclement weather and holidays, the construction of the asphalt concrete overlay was delayed for several days after the membrane application. The thickness of the overlay was to be 3 inches, which is not considered to be a thin overlay. Therefore it was expected that reflective cracking might take longer to appear than it would if the overlay had been thinner.

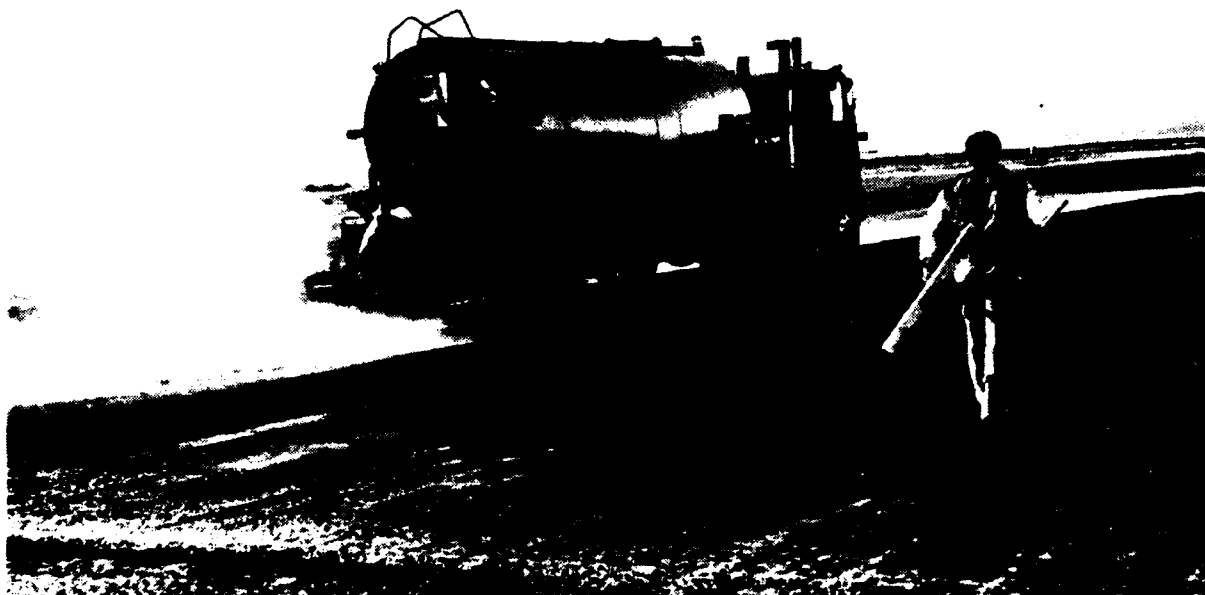


Figure 16. Asphalt-Rubber Application.

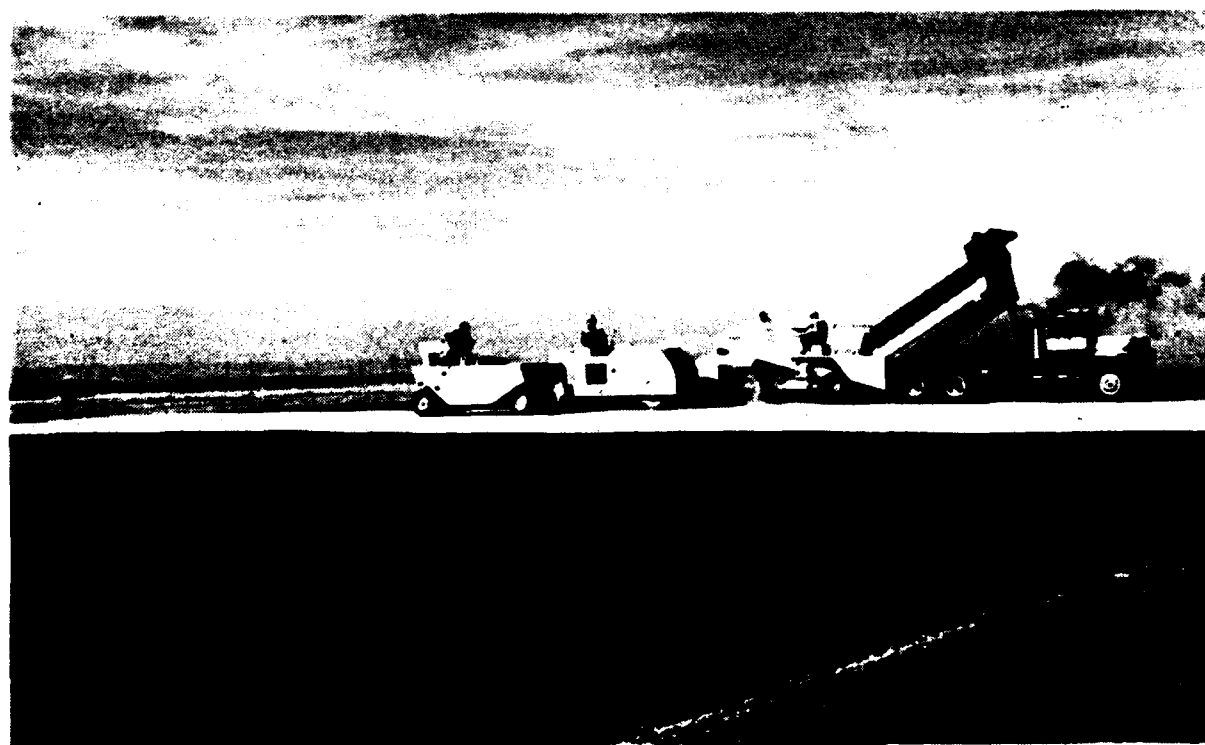


Figure 17. Aggregate Application and Embedment Operation.



Figure 18. Finished Asphalt-Rubber Membrane.

ASPHALT-RUBBER PROPERTIES

Asphalt-rubber samples were taken from the distributor trucks immediately before the addition of diluent and after the appropriate mixing time before laydown. The samples containing no diluent were designated as control samples. All samples were transported to the laboratory for immediate testing. The tests performed on these materials were the modified softening point, constant pressure viscosity, and force-ductility. The samples were poured in thin layers of approximately 0.25 inches and allowed to cure under ambient conditions. Testing was conducted at 2-, 8-, and 26-week periods. The data for these materials are located in Tables B-5 through B-12 in Appendix B.

Modified Softening Point

Figures 19 through 21 show that in all the mixtures the modified softening point temperature increased over the 26-week testing period. The most dramatic increase was for the CPR-10P, 2.7-hour mixture which increased from 80°F to 120°F. For all the rubbers the order of softening point temperature at 26 weeks from highest to lowest was the control sample followed by the

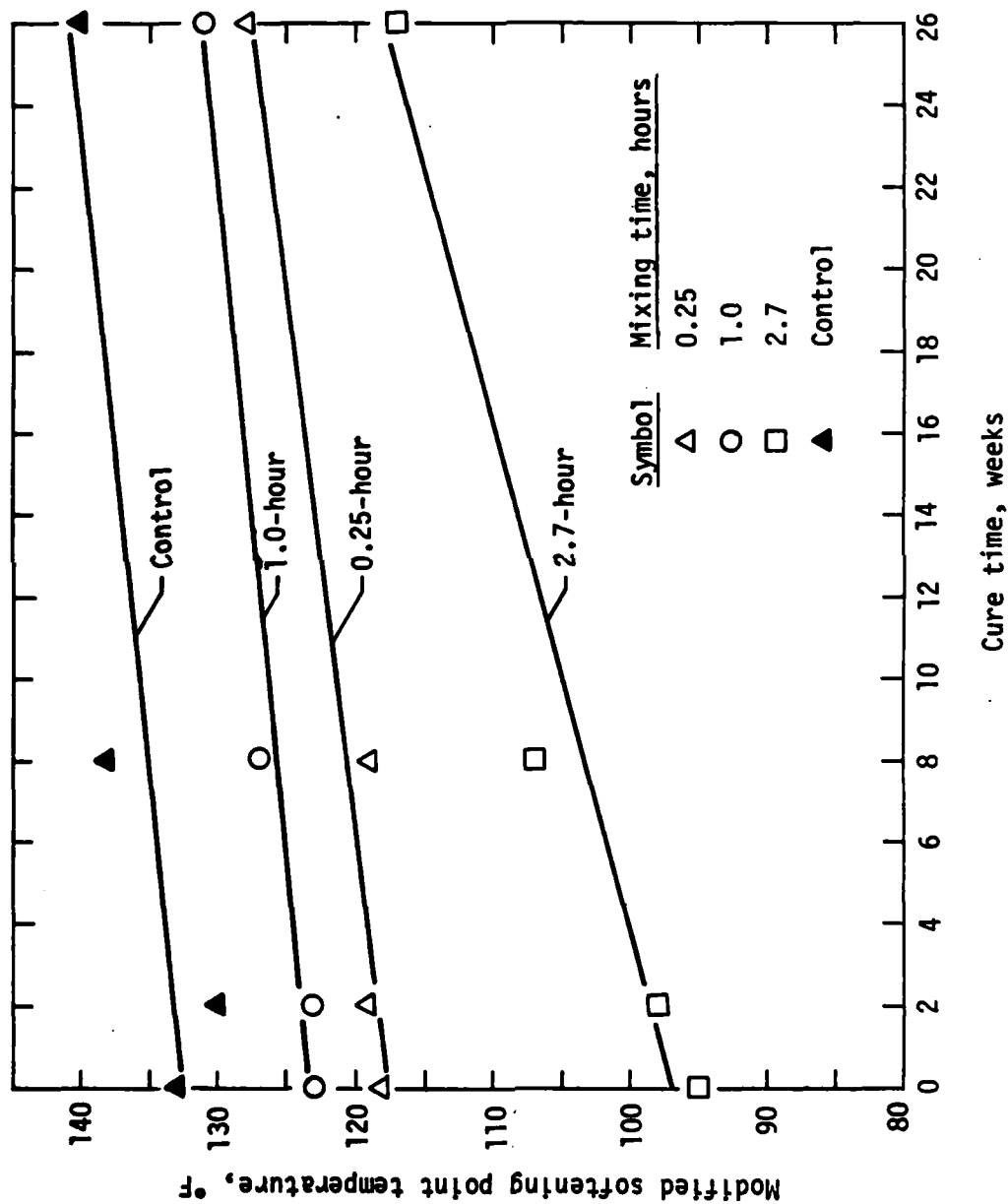


Figure 19. Modified Softening Point Versus Cure Time for TP044.

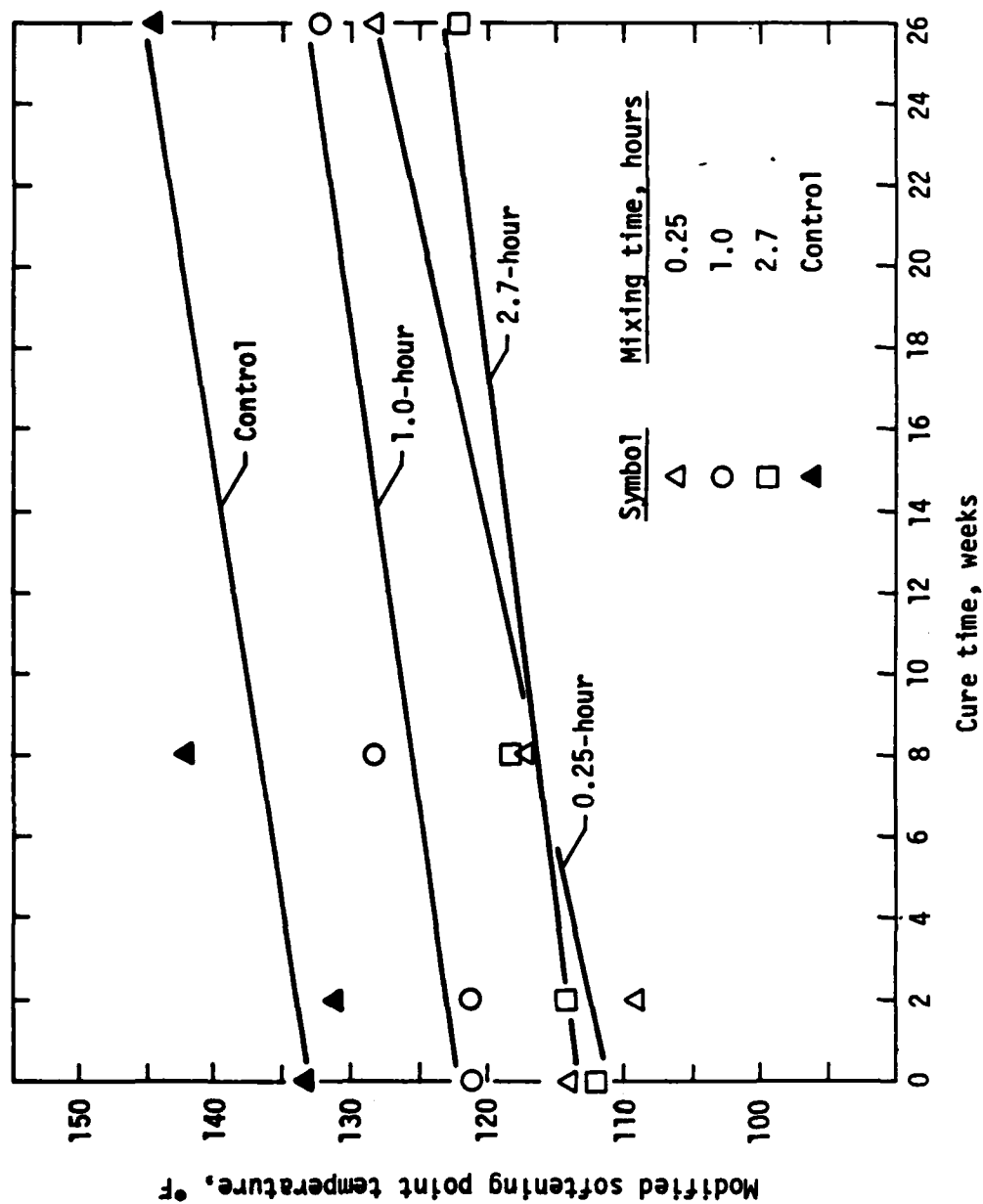


Figure 20. Modified Softening Point Versus Cure Time for C-104.

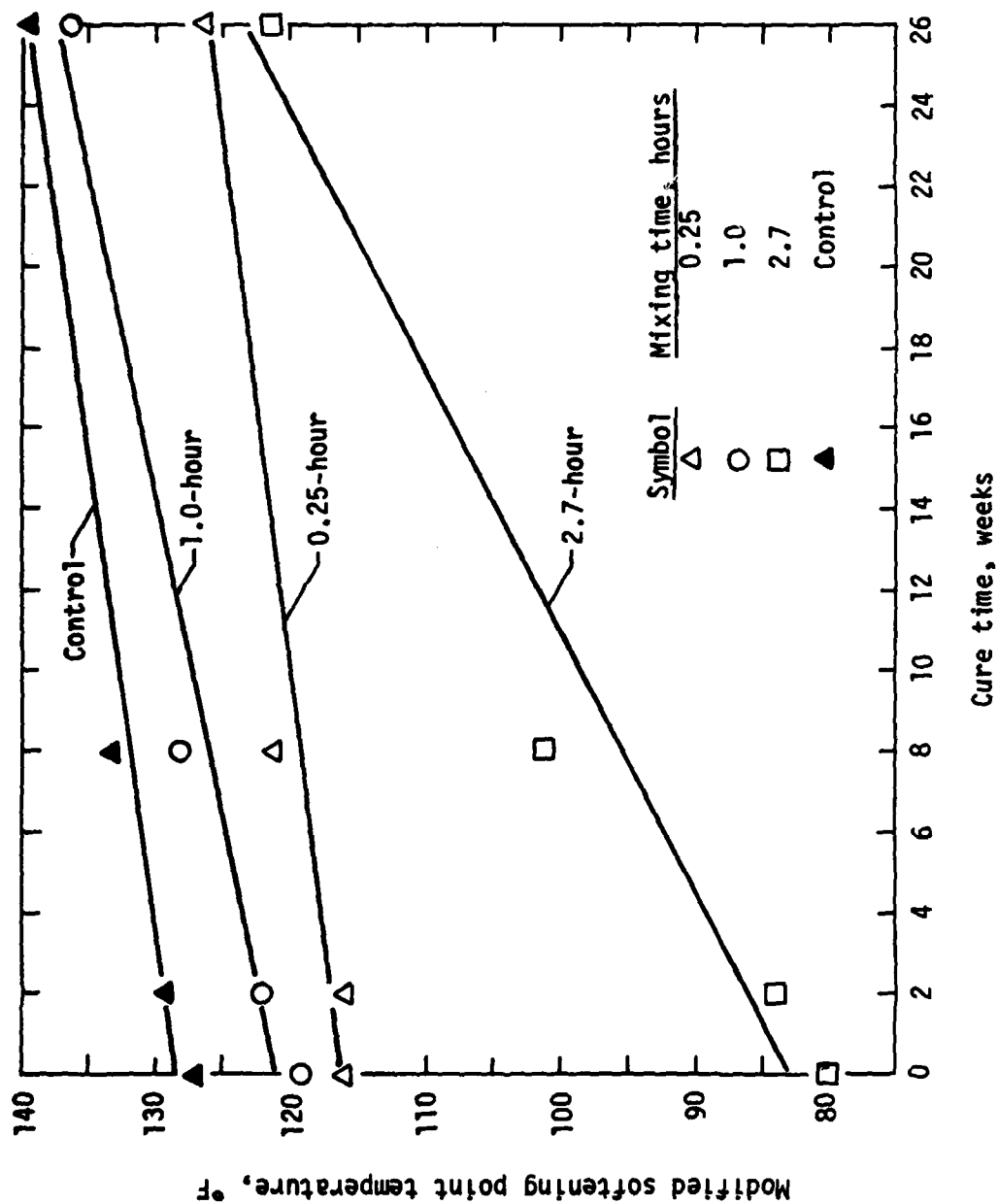


Figure 21. Modified Softening Point versus Cure Time for CPR-10P.

1-hour, 0.25-hour, and 2.7-hour mixtures, respectively. No differences were evident in the values for the rubber types except that the 2.7-hour mixing time may have had a greater initial impact upon the TP044 and CPR-10P mixtures than the C-104 mixture. Note that the control samples all increased in modified softening point temperature, even in the absence of diluent. This may indicate a continuing reaction between the asphalt and rubber.

The softening point results presented in this study do not match the results from the laboratory study. In the laboratory it was observed that mixtures manufactured with TP044 had higher softening point temperatures than C-104 or the cryogenic rubber. No indication of this was observed in the field-mixed material.

It was also noted in the laboratory study that there was no difference between softening point temperatures for the 1-hour and 4-hour mixing times and that the 0.5-hour mixing time produced the lowest softening point. In this study the 2.7-hour mixtures had the lowest softening point, in general, and the 1-hour mixtures consistently had the highest softening point of the materials placed in the field trial. In the laboratory study the lowest softening point temperature of all the mixtures was 142°F for the 0.5-hour cryogenic rubber mixture. Of the material used in the test sections, the lowest softening point value was 80°F for the 2.7-hour cryogenic rubber at construction.

These differences may be attributed to the differences in preparation of laboratory and field mixtures. In the laboratory, asphalt-rubber was manufactured under very controlled conditions at 375°F. Mixing temperatures in the field ranged from 310°F to 340°F. The asphalt in the field was preheated to 425°F, whereas asphalt in the laboratory was preheated to the 375°F mixing temperature. No diluent was added to the laboratory mixtures. The materials placed in the field trial had between 2 and 5 percent diluent added to them.

The Arizona Department of Transportation (ADOT) used a ring-and-ball apparatus to measure softening point (Reference 17). ADOT also concluded that for mixtures containing diluent, the softening point increased with cure time. Softening point as determined by the ring-and-ball method seems to result in higher temperatures than the modified method.

Compliance

The value of compliance versus cure time is shown in Figures 22 through 24. The compliance of the test section mixtures generally decreased with time. Note, however, that the values for the control mixtures remain relatively constant. The TP044 and C-104 mixtures produced very distinct compliance-time curves. However, at the end of 26 weeks the CPR-10P control 1 hour and 0.25-hour mixtures had converging compliance values. The order of increasing compliance according to mixing time for all the rubber types was the control 1-hour, 0.25-hour, and 2.7-hour mixtures. This might be expected from a review of the softening point data. There are no obvious trends according to the rubber types used in the mixtures.

These data show agreement with those presented in a study by ADOT (Reference 17). The conclusions from that study indicated that as cure time increased, the compliance decreased. Another parallel conclusion is that up to 168 hours of accelerated curing or 26 weeks of ambient curing there is little effect upon mixtures containing no diluent. In another study conducted by ADOT (Reference 18) it was shown that increased reaction time increased the compliance, as was also seen in this study.

Figure 25 reveals a correlation between the compliance and modified softening point values. The equation for the linear regression is

$$\log D(t) = 2.3135 - (0.0326) SP \quad (9)$$

where

$D(t)$ = compliance, psi^{-1}

SP = modified softening point temperature, $^{\circ}\text{F}$

The correlation coefficient between compliance and softening point was 0.93. Therefore the value of the softening point could potentially be used to estimate asphalt-rubber compliance.

Viscosity

All the mixtures, including the control mixtures, increased in viscosity with increasing cure time. This is shown in Figures 26 through 28. The

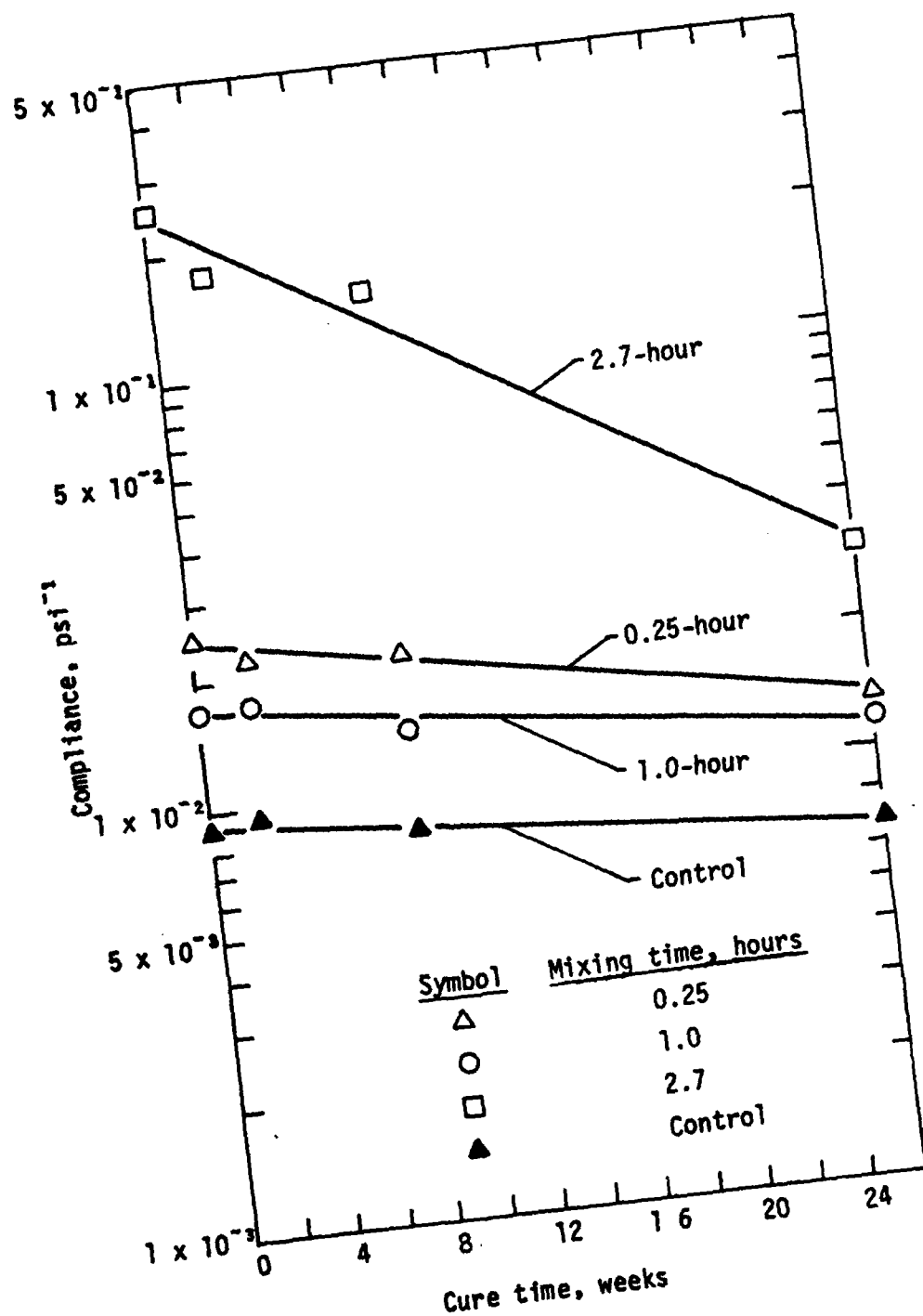


Figure 22. Compliance versus Cure Time for TP044.

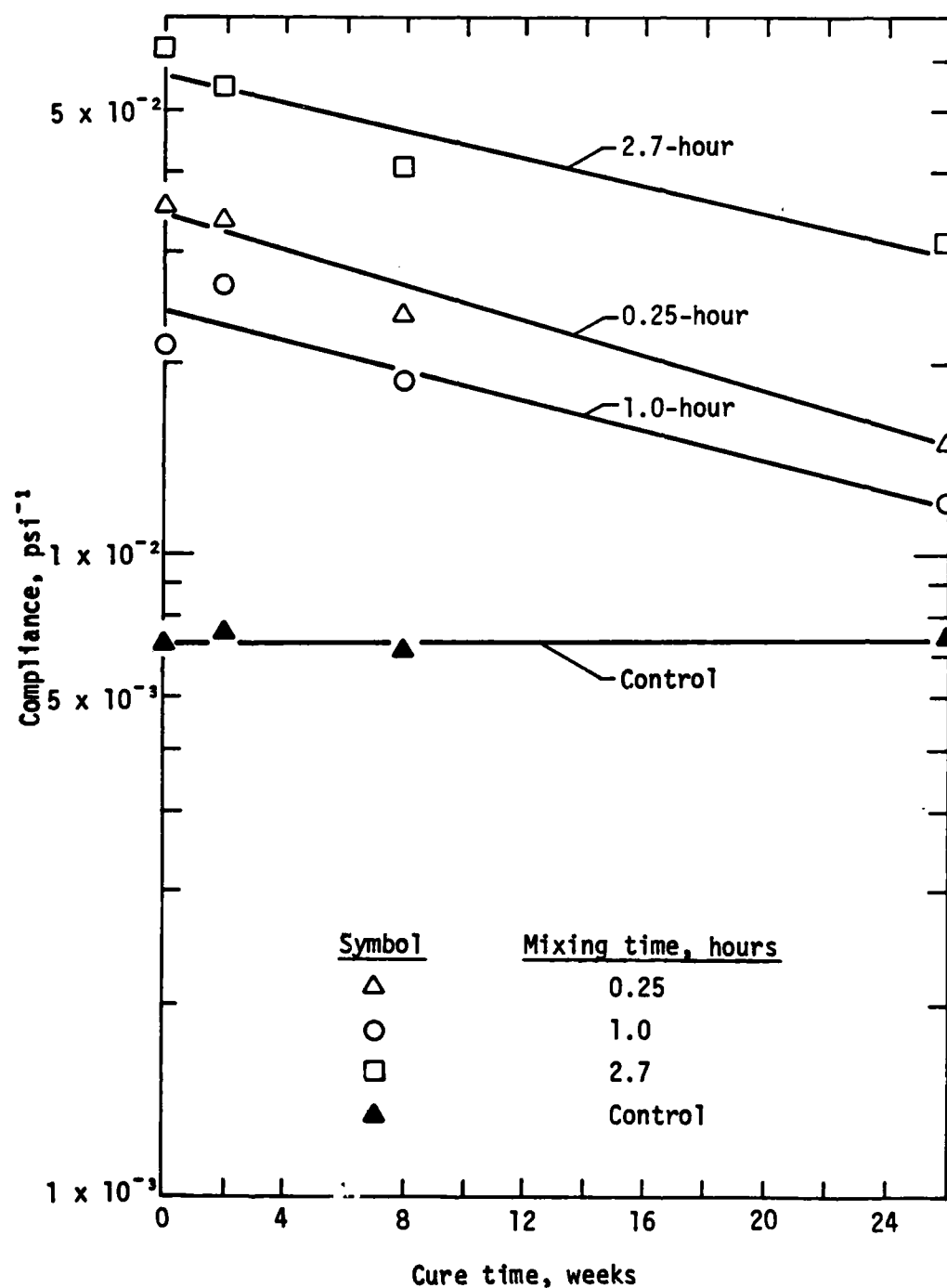


Figure 23. Compliance versus Cure Time for C-104.

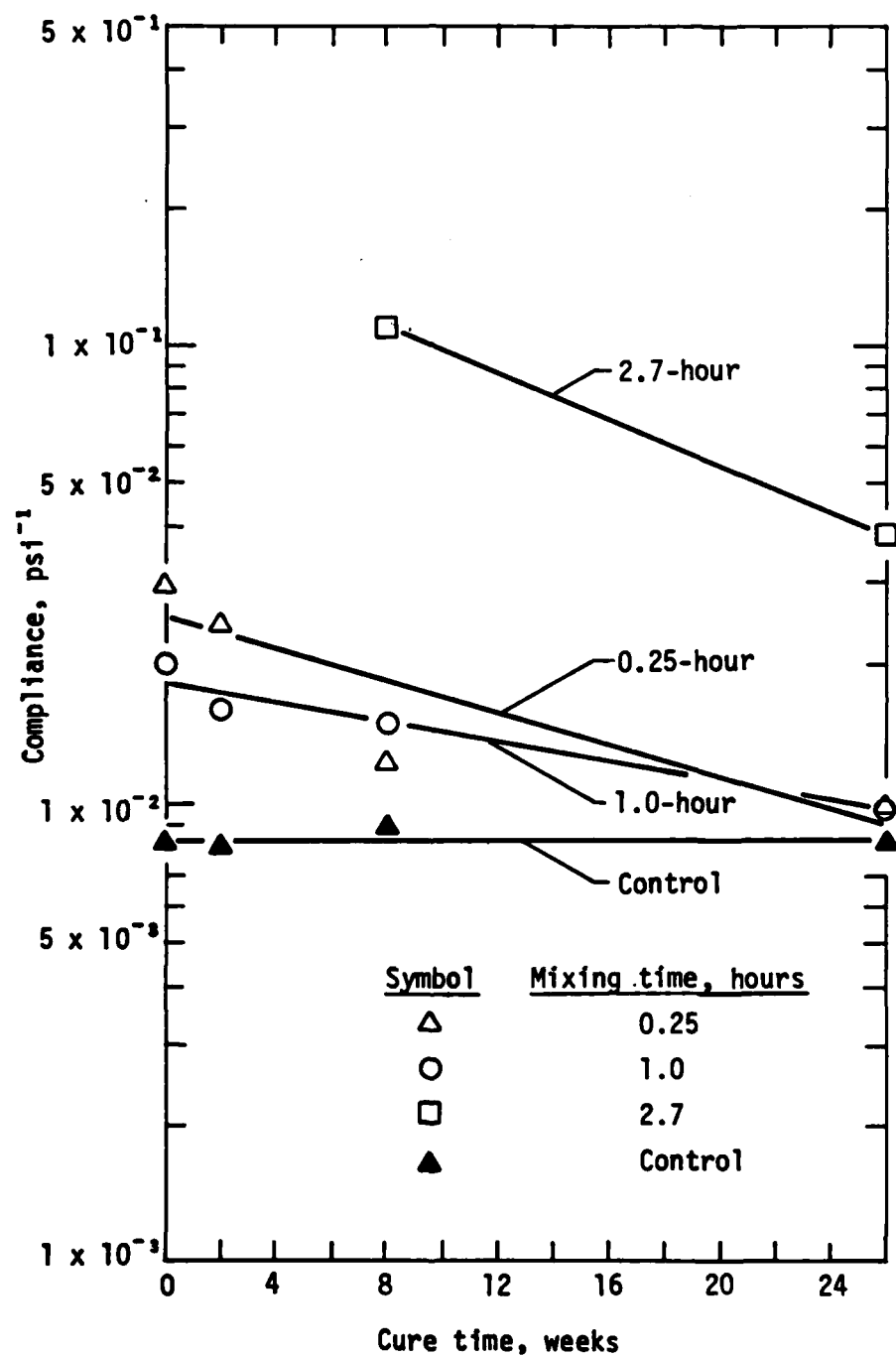


Figure 24. Compliance versus Cure Time for CPR-10P.

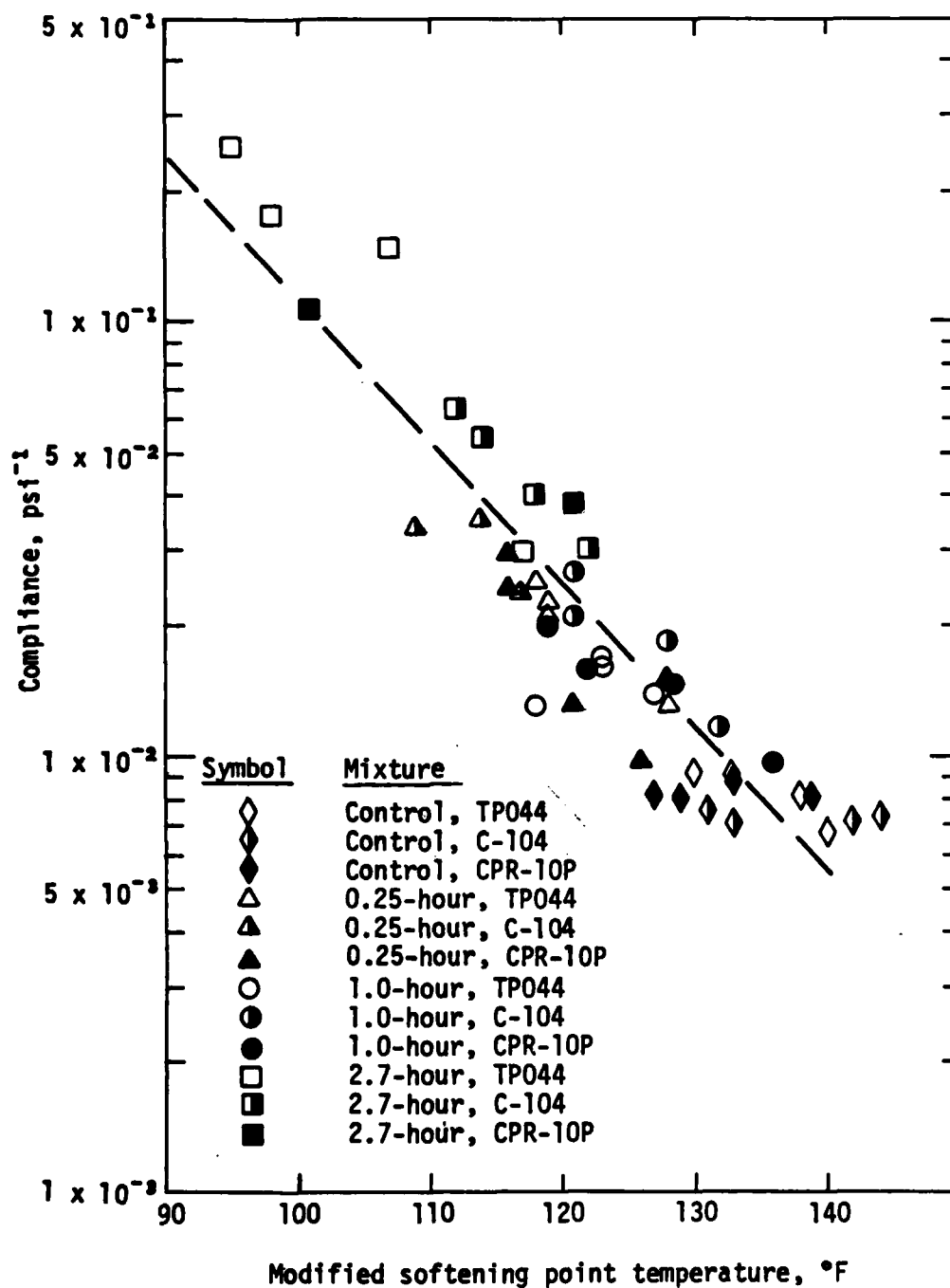


Figure 25. Compliance versus Modified Softening Point Temperature.

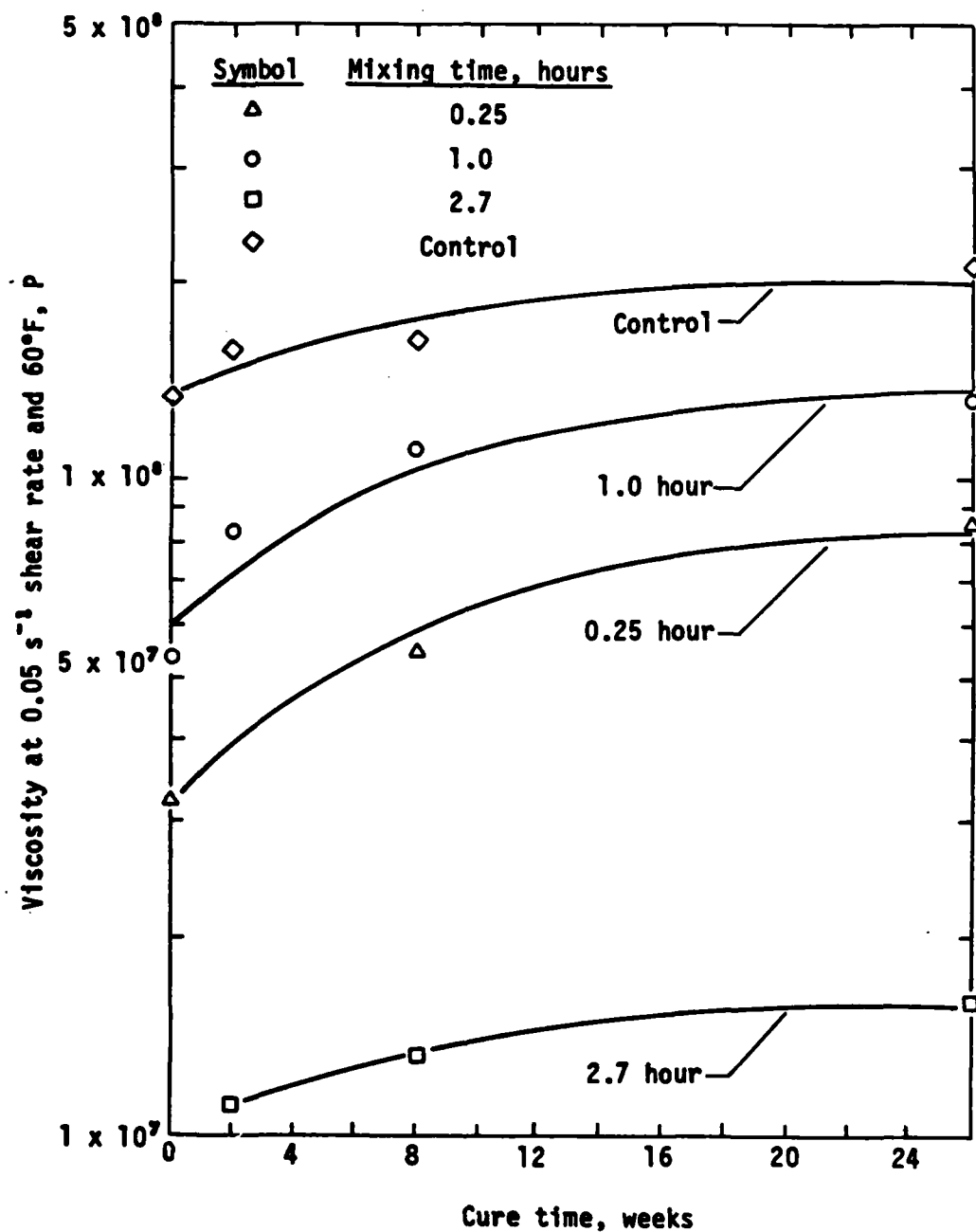


Figure 26. Viscosity at 0.05 s^{-1} Shear Rate and 60°F versus Cure Time for TP044.

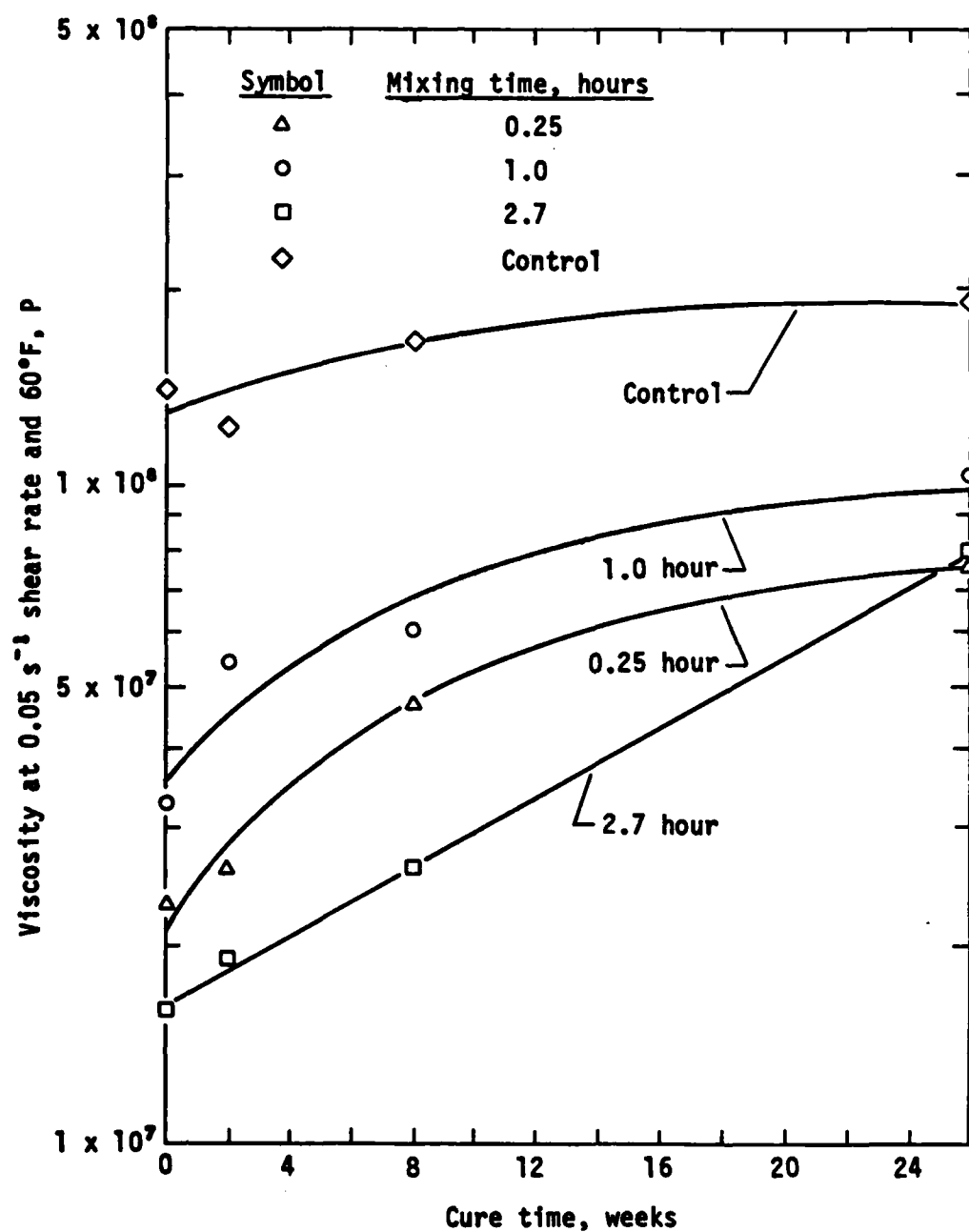


Figure 27. Viscosity at 0.05 s^{-1} Shear Rate and 60°F versus Cure Time for C-104.

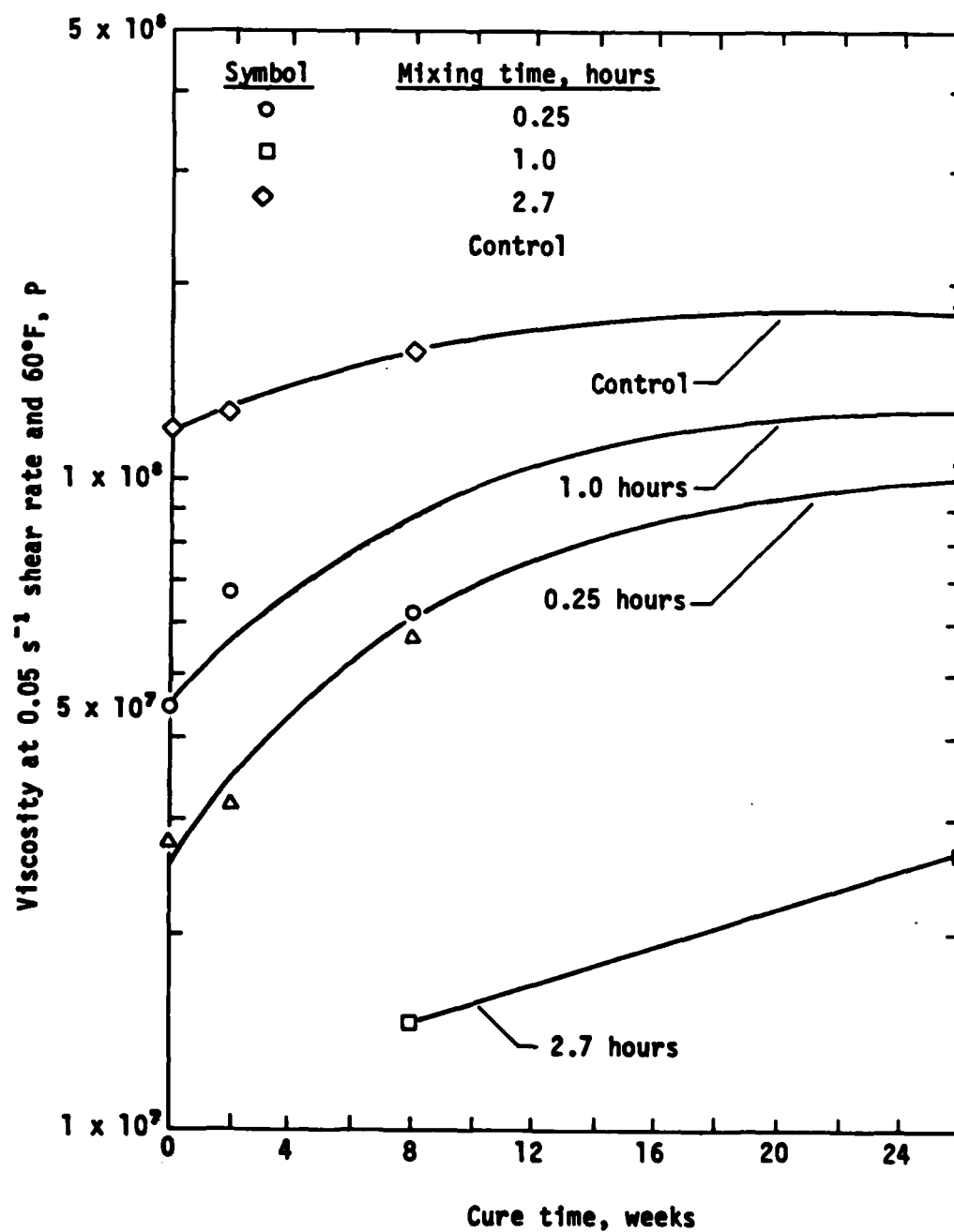


Figure 28. Viscosity at 0.05 s^{-1} Shear Rate and 60°F versus Cure Time for CPR-10P.

order of increasing viscosity of the mixtures is generally the 2.7-hour, 0.25-hour, 1-hour, and control mixtures for all the rubber types. The greatest effects of mixing times on viscosity are for 2.7-hour mixtures containing TP044 and CPR-10P. The 2.7-hour mixing time did not have as dramatic an effect on the C-104 mixture. At the end of 26 weeks the 2.7-hour, C-104 mixture had the same viscosity as the 0.25-hour mixture of the same rubber type.

Figure 29 shows the relationship between viscosity at 0.05 s^{-1} and the modified softening point temperature for the materials used in the field trial. For these data the regression equation is

$$\log \eta_{0.05} = 3.6911 + (0.0330) \text{ SP} \quad (10)$$

where

$\eta_{0.05}$ = viscosity at 0.05 s^{-1} shear rate and 60°F

SP = modified softening point temperature, $^\circ\text{F}$

The correlation coefficient was 0.93, which shows that there is a good relationship between the two parameters. Therefore it is possible that the softening point temperature may be a valuable tool in predicting the viscosity of asphalt-rubber mixtures.

Comparisons of Laboratory and Field Mixtures

Table 4 presents a comparison of the properties of the 1-hour laboratory mixtures in Matrix III and properties of the 1-hour field mixtures. Initially all the field mixtures had softening point values of about 80 percent of the laboratory mixtures. After curing 26 weeks the field mixtures had softening point values of between 85 and 91 percent of the laboratory mixtures. The compliance of the field mixtures initially had values of between 290 and 709 percent of their laboratory counterparts. These percentages decreased to between 200 and 233 percent after 26 weeks. The viscosities of the field mixtures at the time of construction ranged between 2 and 15 percent of the laboratory mixtures' viscosities. This increased to 36 percent for the TP044 mixtures, 14 percent for the C-104 mixture, and only 9 percent for the APC-10 mixture.

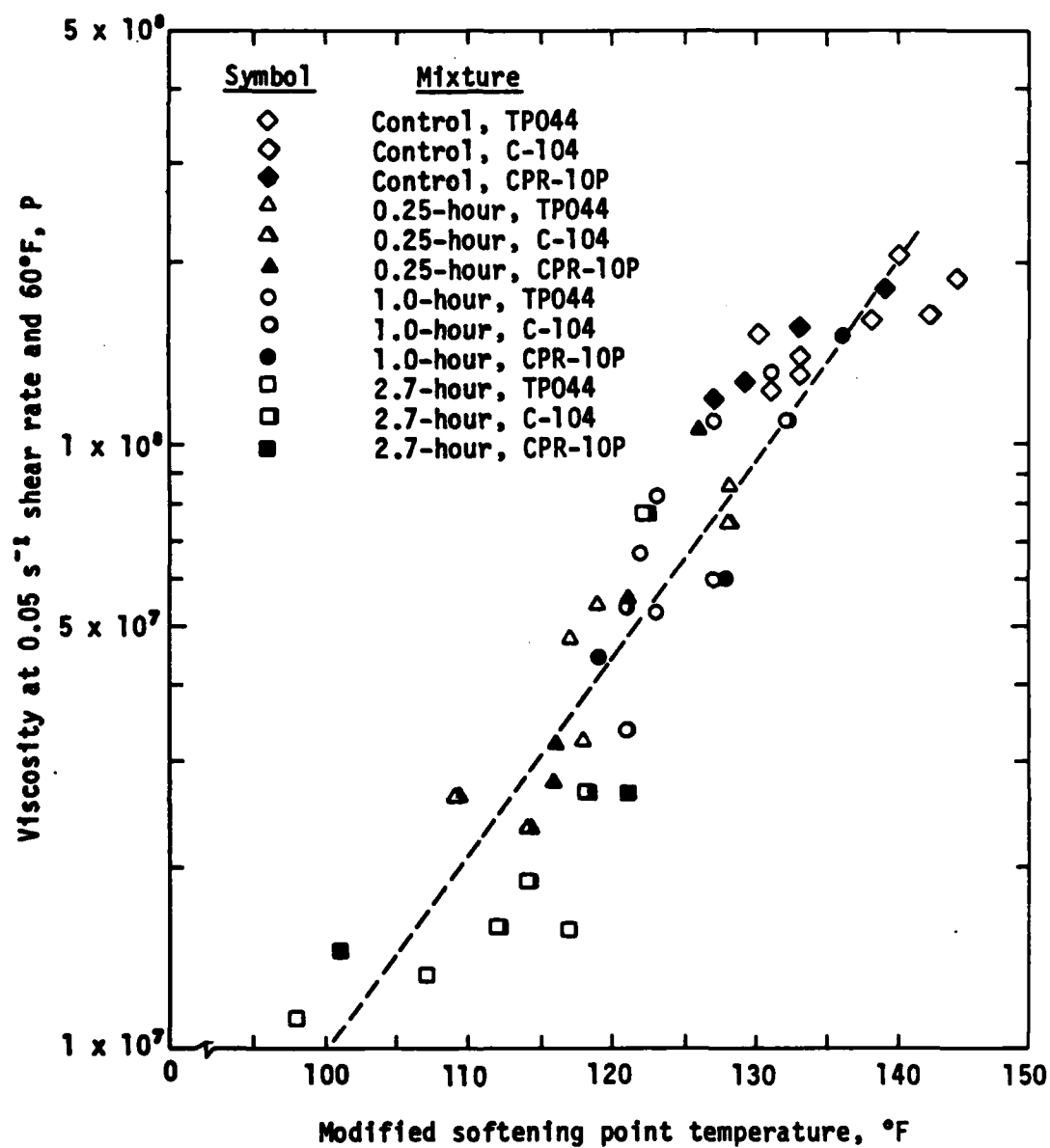


Figure 29. Viscosity at 0.05 s^{-1} Shear Rate and 60°F versus Modified Softening Point Temperature.

TABLE 4. COMPARISON OF 1-HOUR MIX TIME LABORATORY MIXTURES AND 1-HOUR MIX TIME FIELD MIXTURES AT 0- AND 26-WEEK CURE TIMES

Rubber Type	Modified Softening Point Temperature, °F				Compliance at 39.2°F, 10 ⁻⁴ psi ⁻¹				Viscosity at 0.05 s ⁻¹ Shear Rate and 60°F, 10 ⁶ P					
	Lab.	Field			Lab.	Field			Lab.	Field				
		0-week	% of Lab.	26-week % of Lab.		0-week	% of Lab.	26-week % of Lab.		0-week	% of Lab.	26-week % of Lab.		
TP044	154	124	80	131	85	59	171	290	118	200	3.6	15	1.3	36
C-104	146	121	83	133	91	54	214	396	119	220	7.1	5	1.0	14
APC-10	152	119	78	136	89	42	298	709	98	233	17	2	1.5	9

CRACK SURVEY

Crack surveys of the field trial were made once every 6 months from the time of construction. The initial survey showed that no cracking had occurred. One year after construction, 20 cracks were found in the pavement. The majority of these were located in the control section which had been completely rebuilt.

The results of the last survey in June 1983 are tabulated in Table 5. Figure 30 shows where these cracks are located on the field trial. Note that, within the test sections, most of the cracks are located in the sections which had 2.7-hour mixing times. However, it cannot be concluded that these are necessarily reflective cracks. This pavement is in excellent condition.

The cracks shown in the completely rebuilt control section may be attributed to heavy fuel truck traffic from a nearby fuel depot.

TABLE 5. APRON A CRACK SURVEY, JUNE 1983

Crack No.	Station No.	Distance from East Edge of Pavement, ft	Type ^a	Length, ft	Severity ^b	Remarks
1	1+57	38.58	T	1.33	L	Joint
2	1+58	38.58	T	1.33	L	
3	1+58	38.58	L	1.25	L	
4	2+88	76.5	L	4.0	L	
5	4+10	39.10	T	1.0	L	
6	4+26	14.0	L	0.5	L	
7	4+26	14.5	L	0.92	L	
8	4+26	34.92	L	14.17	L	
9	5+11	37.0	L	0.92	L	
10	5+25	36.0	L	10.58	L	
11	5+31	20.0	L	10.17	L	
12	5+34	9.25	T	0.66	L	
13	5+34	14.5	L	2.66	L	
14	5+34	15.33	L	1.83	L	
15	5+38	26.83	L	1.58	L	
16	5+80	68.0	L	3.08	L	
17	6+15	65.66	L	2.0	L	
18	6+15	73.0	L	1.0	L	
19	7+31	40.08	L	6.5	L	
20	9+21	106.5	L	4.66	L	
21	10+71	4.25	L	2.5	L	
22	10+71	35.0	L	5.25	L	
23	10+71	93.5	T	2.33	L	
24	10+71	93.33	L	1.25	L	
25	10+88	93.33	L	3.0	L	
26	12+05	89.0	L	0.5	L	
27	12+49	105.0	L	0.66	L	

^aCrack Type: L - Longitudinal
T - Transverse

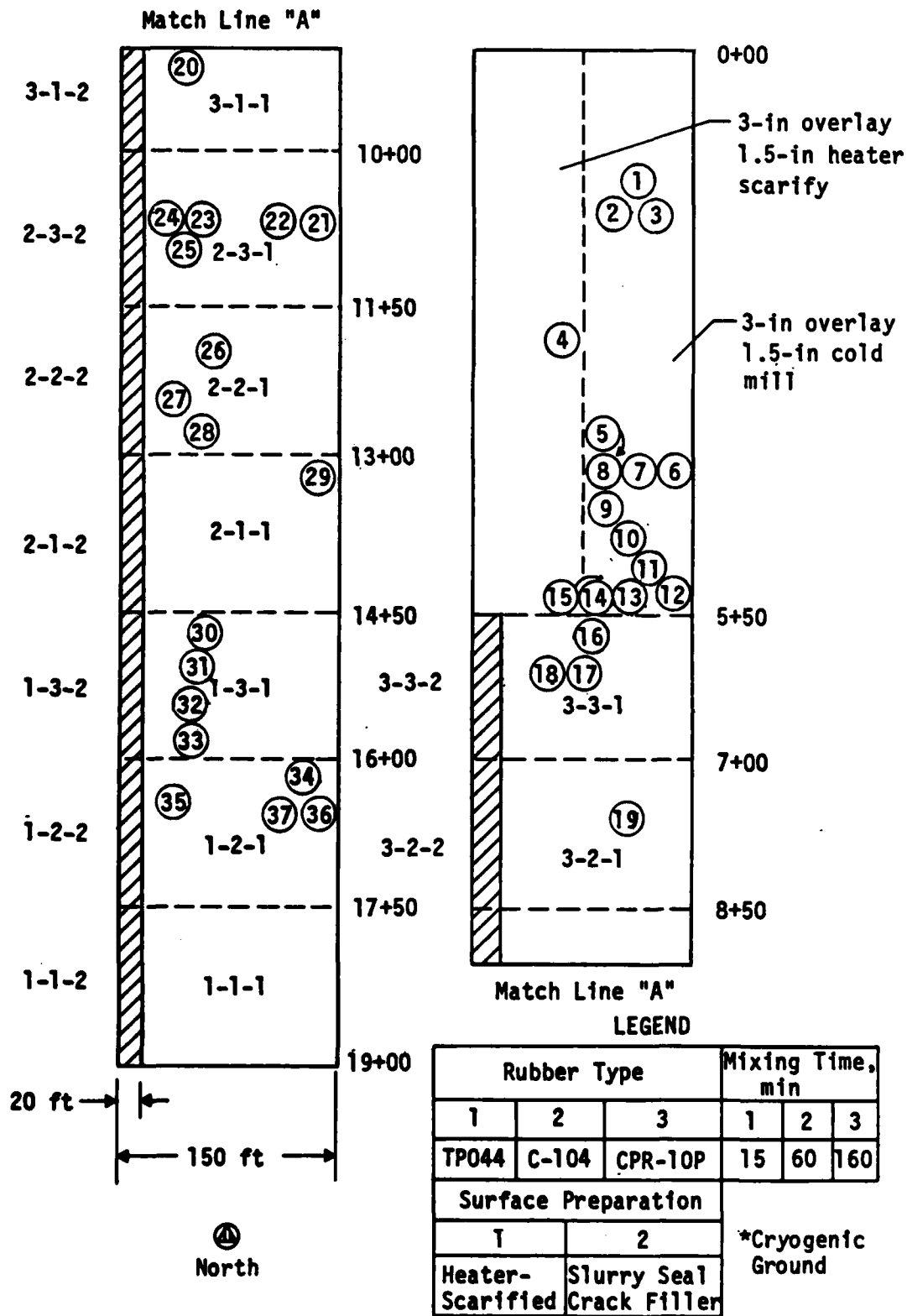
^bSeverity: L - Low
M - Medium
H - High

TABLE 5. APRON A CRACK SURVEY, JUNE 1983 (CONCLUDED)

Crack No.	Station No.	Distance from East Edge of Pavement, ft	Type ^a	Length, ft	Severity ^b	Remarks
28	12+74	95.0	L	1.17	L	Joint
29	13+12	6.0	L	3.17	L	
30	14+76	89.5	L	2.66	L	
31	14+78	89.5	L	0.83	L	
32	15+54	92.5	L	7.17	L	
33	15+91	92.5	L	4.33	L	
34	16+09	26.0	L	8.08	L	
35	16+32	114.5	T	3.0	L	
36	16+37	9 33	L	0.05	L	
37	16+37	10.5	L	0.58	L	

^aCrack Type: L - Longitudinal
T - Transverse

^bSeverity: L - Low
M - Medium
H - High



Circled numbers correspond to Crack No. in Table 5.

Figure 30. Results of Crack Survey, Apron A, June 1983.

SECTION V

TIME-TEMPERATURE STUDY

The properties of asphalt-rubber are time- and temperature-dependent, as they are for asphalt cement. Therefore it was important to investigate the behavior of asphalt-rubber mixtures at various temperatures and rates of deformation. Two experiments were established to accomplish these ends. In Matrix III the mixtures were tested at 30°, 55°, and 80°F for constant pressure viscosity and force-ductility properties. Only the force-ductility test was used to characterize the sample rate-dependency of the asphalt-rubber mixtures in Matrix IV. These sample rates were 0.08, 0.32, and 1.61 in/min.

In these experiments all the mixtures were prepared at a mixing temperature of 375°F for a period of 1 hour. The reclaimed rubbers were TP044, C-104, and APC-10 as described in Section II. Three different grades of asphalt cement were used in this part of the project. These were AC-5, AC-10, and AC-20. The properties of these asphalts may be found in Table 1, Section II. The asphalt-to-rubber ratios were 75 to 25.

MATRIX III

This experiment was performed to establish the temperature dependency of the asphalt-rubber mixtures for viscosity and force-ductility. The data from this part of the research program are found in Tables B-13 and B-14, Appendix B.

Figure 31 shows constant power viscosity versus test temperature for all the mixtures. Notice that the asphalt grade exerted a greater influence on viscosity than did the rubber type. For AC-5 mixtures viscosity values ranged from about 9×10^7 poises at 80°F to approximately 5×10^{10} poises at 30°F. This range was from 1.6×10^8 poises at 80°F to 7.6×10^8 poises at 30°F for AC-10 mixtures. AC-20 mixtures went from a low viscosity of 2.5×10^8 poises at 80°F to about 1.2×10^{11} poises at 30°F. Traxler (Reference 30) observed that as the temperature of the viscosity measurement is raised the non-Newtonian characteristics of asphalts decrease. A brief review of the values

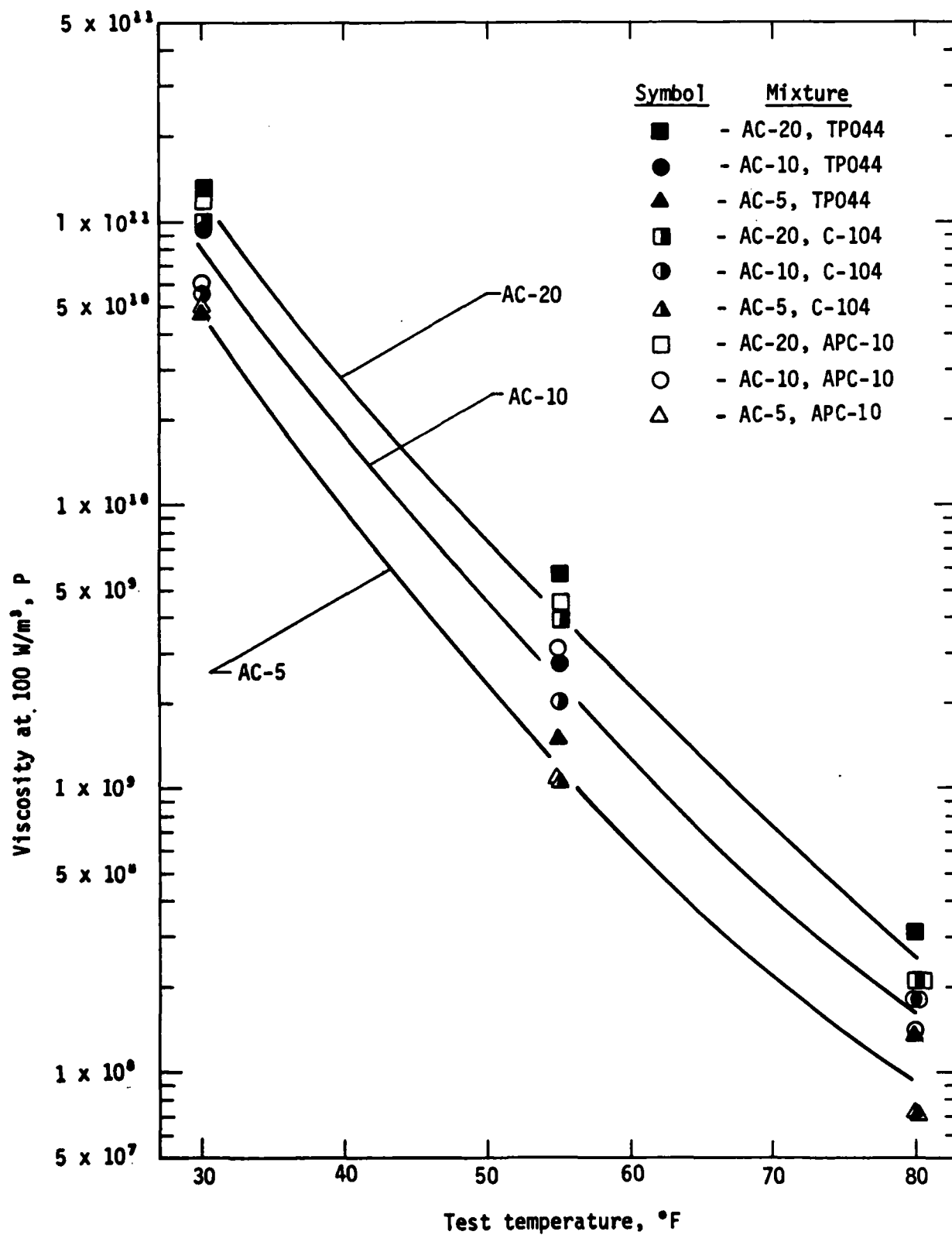


Figure 31. Viscosity at 100 W/m² versus Test Temperature.

of the complex flow parameters in Table B-13, Appendix B, for the asphalt-rubber mixtures follows this trend in all except two cases (C-104, AC-5, and APC-10, AC-5). However, the standard deviations in both of these cases were high relative to the values of the other mixtures.

Figures C-1 through C-9, Appendix C, show the stress-strain diagrams developed for all the materials used in this study at 30°, 55°, and 80°F. All force-ductility tests in Matrix III were run at a sample deformation rate of 0.32 in/min. In all cases, as might be expected, as the test temperature increased the values of true stress decreased. Note that the values of strain at maximum stress do not follow a consistent trend with respect to the test temperatures. In fact, most of the values of strain at maximum stress fall within a fairly narrow range for a given mixture. The largest difference of 40 percent for this value occurred with the APC-10, AC-5 mixture. From Table B-13, Appendix B, note that this material had the largest strain standard deviation at 80°F.

Compliance for all the mixtures decreased with decreasing test temperature as can be seen in Table B-13. This means that the materials became stiffer at lower temperatures, which is expected. This is illustrated in Figure 32 through 34. Mixtures made with AC-20 consistently had the lowest compliance values and those made with AC-5 always had the greatest values. It appears that the APC-10 mixtures were more dependent upon the asphalt grade than the other two rubber types from the range of values shown in Figure 34. The TP044 mixtures (Figure 32) seem to be the least dependent upon asphalt grade. It can also be seen in Table B-13 that the work energy necessary to fracture the samples increased with decreasing test temperatures.

MATRIX IV

As mentioned earlier, the sample deformation rates of the force-ductility tests were varied in this experiment. This was done to ascertain the rate-dependency of the asphalt-rubber mixtures. These tests were performed at a temperature of 39.2°F. The data from this experiment are found in Table B-15.

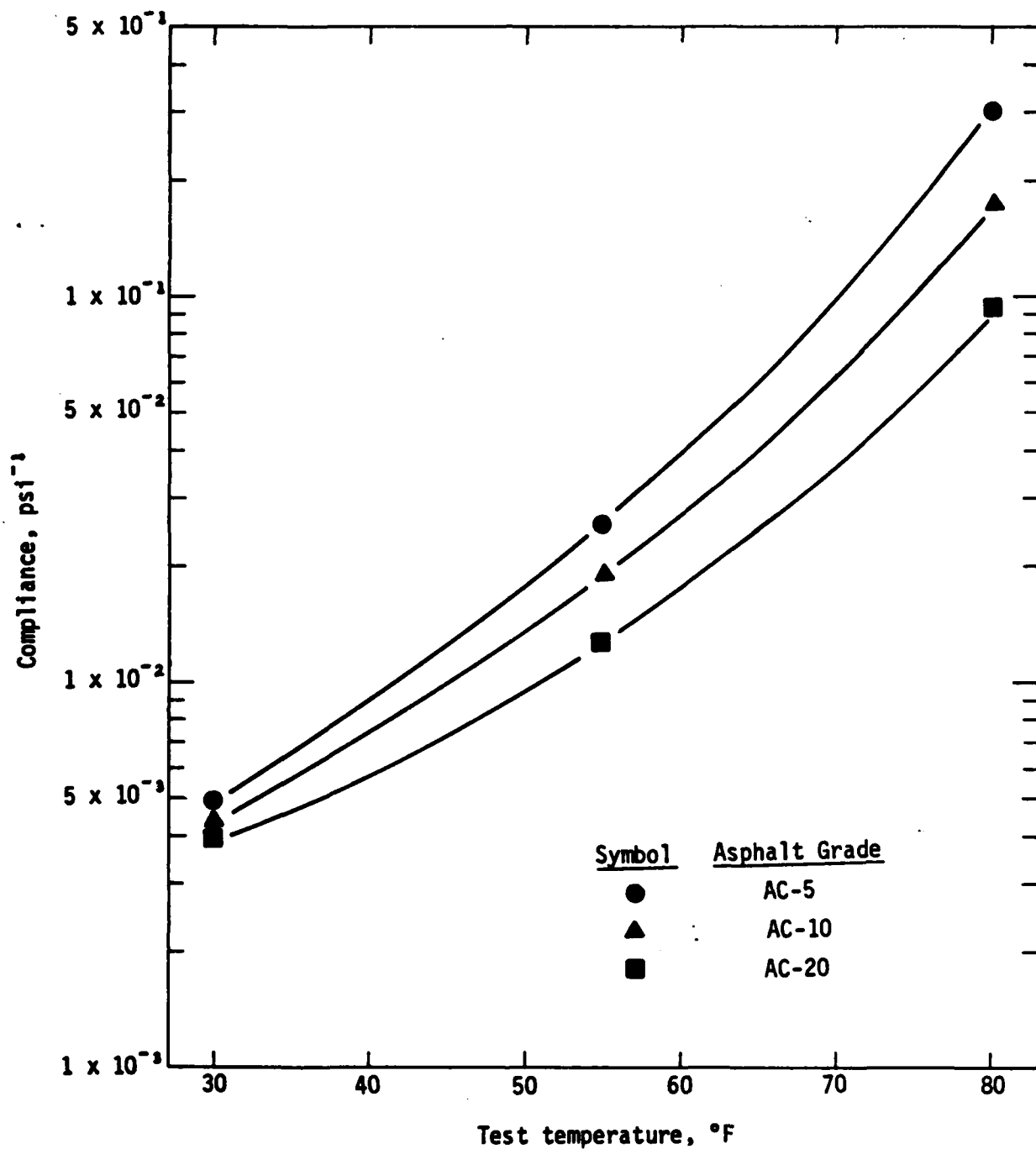


Figure 32. Compliance versus Test Temperature for TP044 Mixtures.

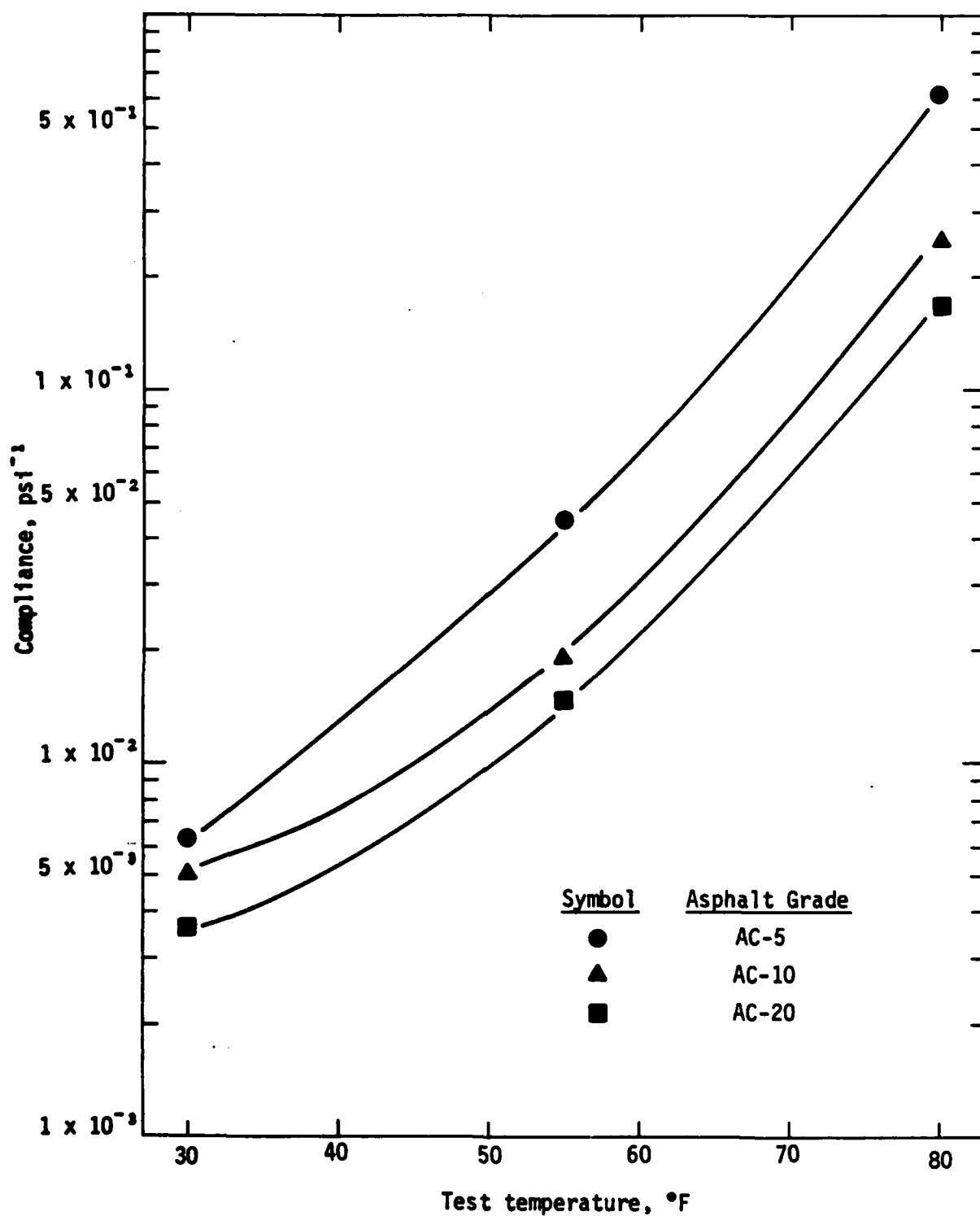


Figure 33. Compliance versus Test Temperature for C-104 Mixtures.

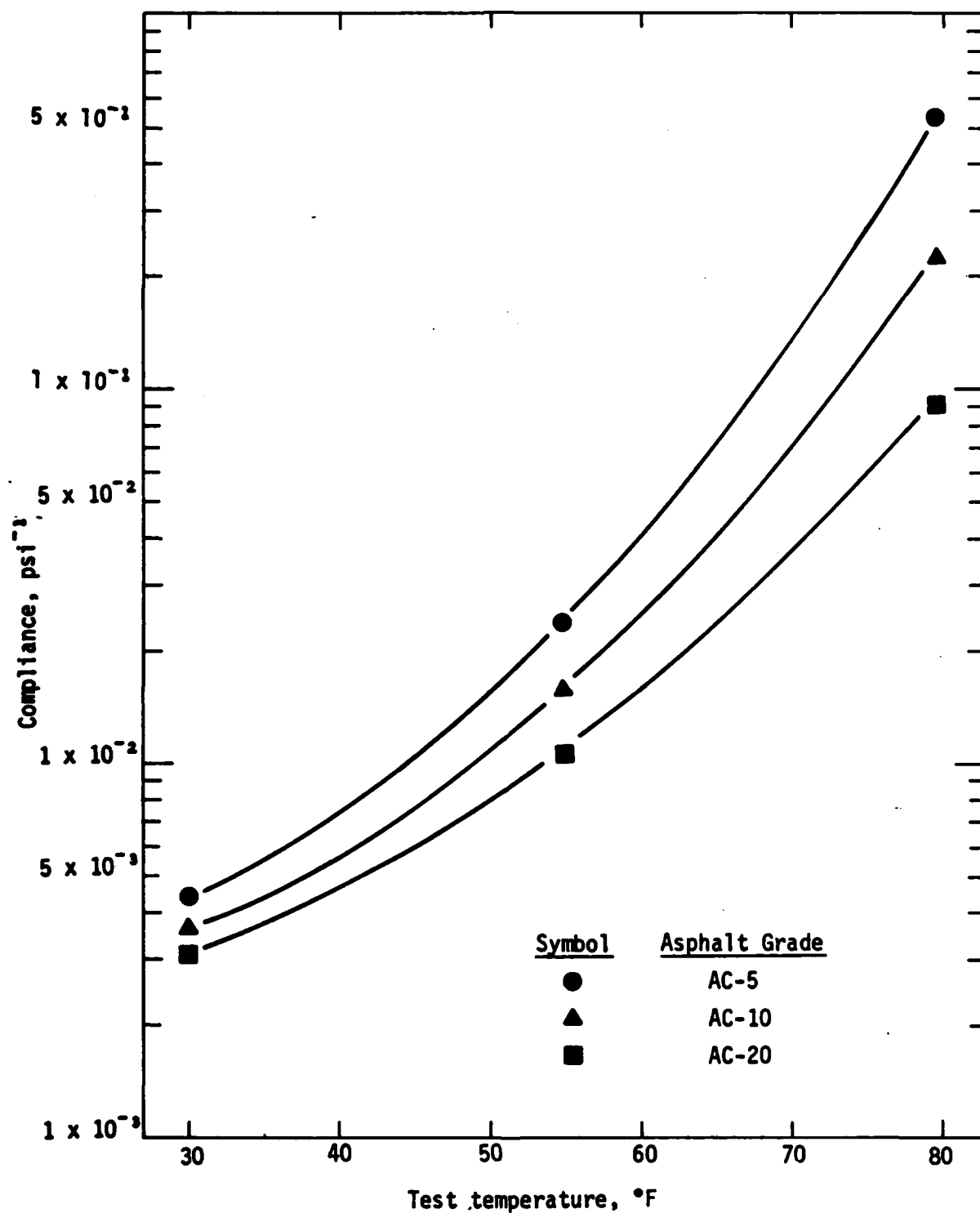


Figure 34. Compliance versus Test Temperature for APC-10 Mixtures.

Figures C-10 through C-18 in Appendix C show the stress-strain curves of the materials at different deformation rates. The stress increased with increasing deformation rates for all the mixtures. Again, as with the temperature experiment, the level of strain at maximum stress showed no consistent trend with respect to deformation rates. The amount of variation in strain at maximum stress between deformation rates for a given mixture was small compared to Matrix III. Compliance of the mixtures decreased with increasing deformation rates as shown in Figures 35 through 37 and work energy to fracture the samples increased with increasing deformation rates. These manifestations of stiffening may be expected since, for viscoelastic materials, materials will exhibit more elasticity at faster rates of loading. In Figure 35 it may be noted that the AC-5, TP044 mixture stiffened more at the 0.32 and 1.61 in/min rates than did the mixture made with AC-10. This was not true in mixtures made with the other rubber types. The only explanation offered for this, outside of experimental error, is that the TP044 mixtures again showed the least dependence upon asphalt grade.

ANALYSES

A multiple linear regression was performed on the stress-strain data of Matrix III and Matrix IV from the nine mixtures used in this study. This was done as an attempt to describe the tensile behavior of the mixtures over the range of temperatures and deformation rates. The model for this regression was:

$$\log \sigma' = b_0 + b_1(\log \epsilon') + b_2(\dot{\delta}) + b_3(T) \quad (11)$$

where

σ' = true stress, psi

ϵ' = true strain, in/in

$\dot{\delta}$ = sample deformation rate, in/min

T = temperature, °F

b_0, b_1, b_2, b_3 = regression coefficients

Table 6 presents the results of these analyses. The correlation coefficients, R , were 0.97 or 0.98 for all the mixtures. This means that for given conditions of sample deformation rate and temperature there was an increase in stress for an increase in strain. The coefficients of variation (CV) ranged from 5.17 to 13.80 percent.

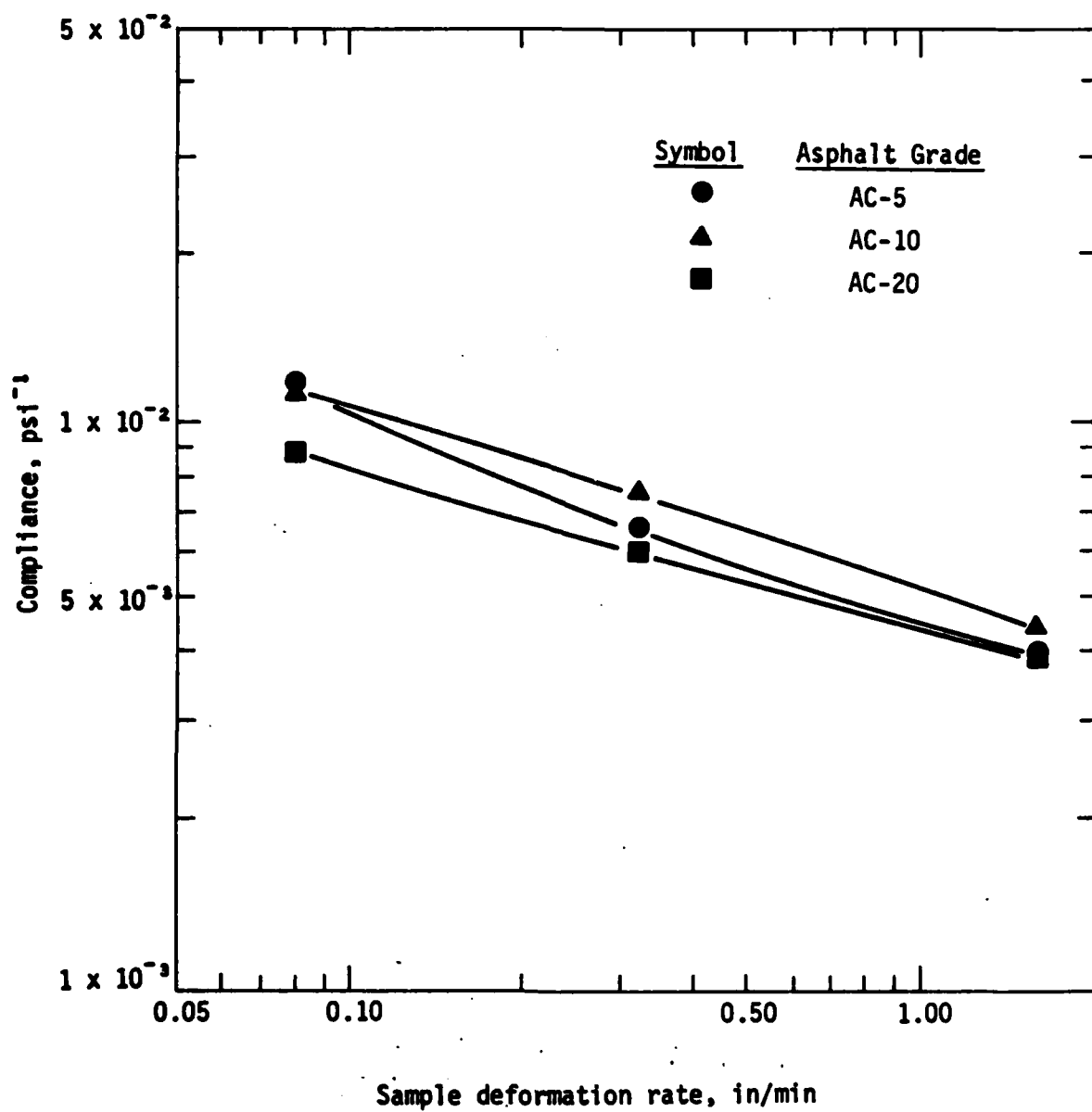


Figure 35. Compliance versus Sample Deformation Rate for TP044 Mixtures.

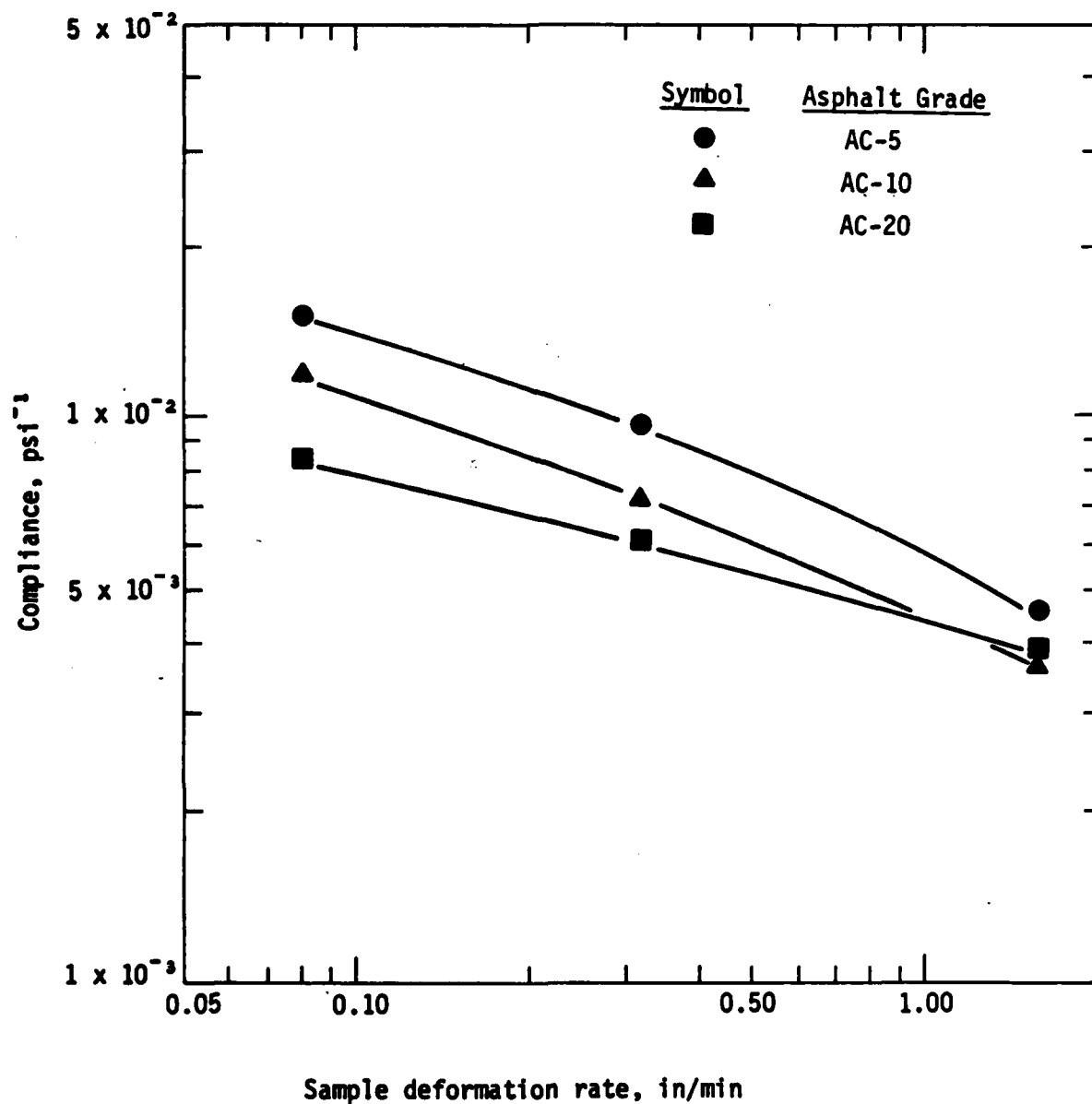


Figure 36. Compliance versus Sample Deformation Rate for C-104 Mixtures.

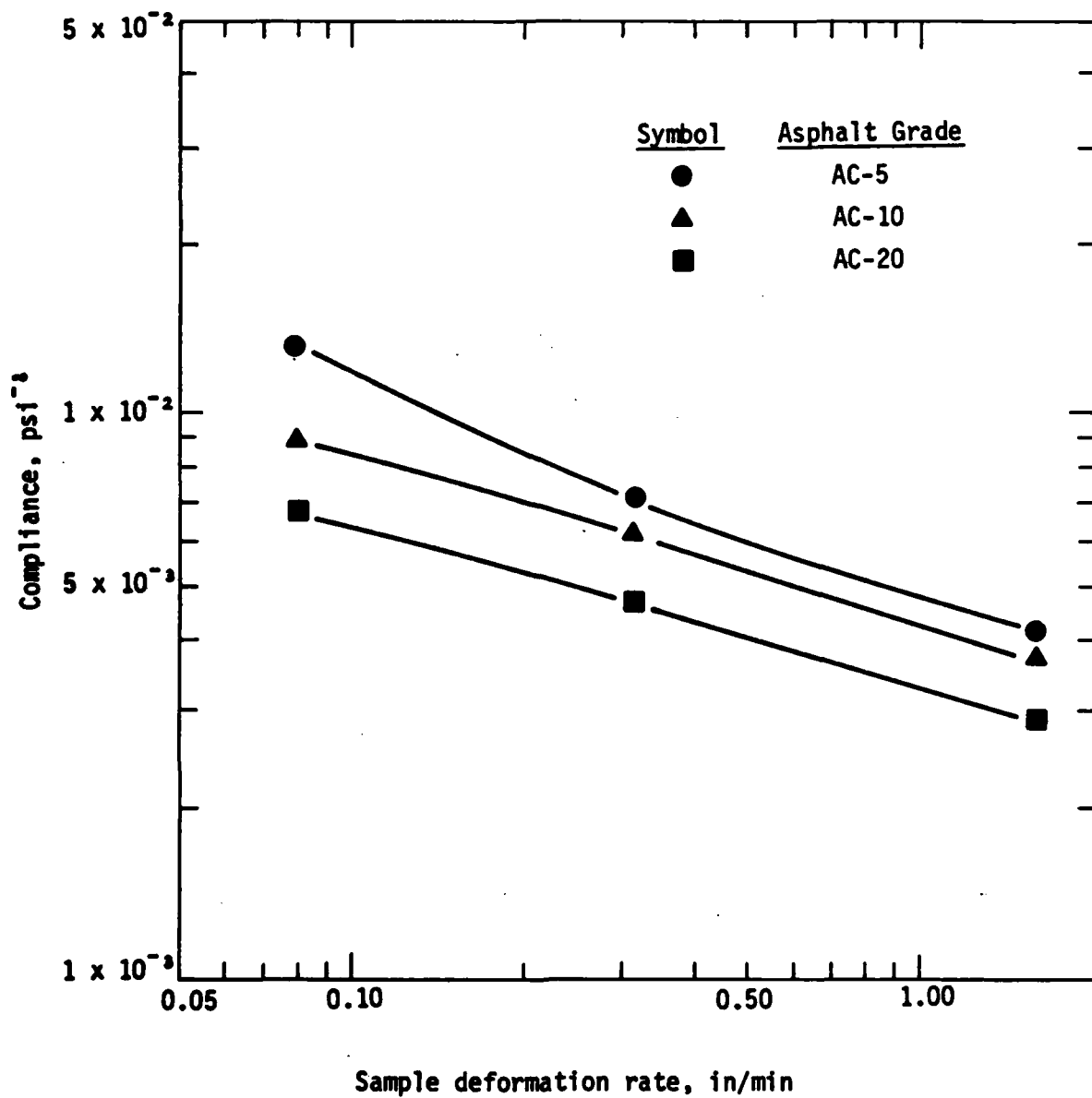


Figure 37. Compliance versus Sample Deformation Rate for APC-10 Mixtures.

TABLE 6. REGRESSION ANALYSES FOR TIME-TEMPERATURE TENSILE EXPERIMENTS^a

Rubber Type	Asphalt Grade	Regression Coefficients				R	CV
		b ₀	b ₁	b ₂	b ₃		
TP044	AC-5	3.1264	0.8186	0.2554	-0.0303	0.98	7.34
	AC-10	3.2173	0.7388	0.2110	-0.0303	0.97	8.32
	AC-20	3.1816	0.7114	0.1844	-0.0268	0.97	7.00
C-104	AC-5	3.3614	0.7266	0.3000	-0.0393	0.98	10.66
	AC-10	3.1966	0.5922	0.2419	-0.0312	0.98	7.49
	AC-20	3.3628	0.6082	0.2007	-0.0320	0.97	8.39
APC-10	AC-5	3.4488	0.5334	0.2773	-0.0390	0.97	13.80
	AC-10	3.3786	0.5303	0.2370	-0.0341	0.98	9.59
	AC-20	3.2130	0.5767	0.2080	-0.0268	0.98	5.17

$$^a\text{Model: } \log \sigma' = b_0 + b_1(\log \epsilon') + b_2(\dot{\epsilon}) + b_3(T)$$

This is a rough attempt to explain the tensile behavior of asphalt-rubber mixtures. The reader will recall that the level of strain at maximum stress was fairly independent of the loading condition for a given mixture of asphalt-rubber. Thus it seems that a logical approach to evaluating the usefulness of this material in a pavement system would be to use a strain-limiting criterion. The material deformation rate might be approximated by computing the rate of contraction of underlying slabs on either side of a crack. The minimum temperature at depth in the pavement may be calculated using Witczak's Equation (Reference 31) at the lowest mean monthly air temperature.

It was beyond the scope of this project to define the mechanisms of reflection cracking in pavement systems. However, an attempt has been made to explain the tensile behavior of asphalt-rubber. It is recommended that the relationships presented here be tried in the evaluation of asphalt-rubbers as interlayers. The authors further believe that the work energy to fracture the material should also be accounted for in the evaluation.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions are made based upon the laboratory study of variables:

1. Laboratory storage conditions (ambient or frozen) up to a 28-day period had no impact on the properties of laboratory-mixed asphalt-rubber formulas.
2. Laboratory storage period had a significant effect upon viscosity data as well as strain and work values. It is not certain if this was due to storage period or laboratory error.
3. The value of true strain at maximum true stress increased with increasing mixing temperature.
4. Compliance of the asphalt-rubber mixtures increased with increasing mixing temperature.
5. Modified softening point temperatures achieved "peak" values at the 375°F mixing temperature for all the rubber types.
6. Viscosities at a constant power of 100 W/m³ also achieved "peak" values at the 375°F mixing temperature.
7. True strain at maximum true stress increased with increasing mixing time.
8. Compliance increased with increasing mixing time.
9. Different laboratory batches produced varying results of work, stress, and strain for the same asphalt-rubber mixtures.
10. Mixtures made with cryogenic rubber exhibited the highest viscosities and lowest compliance values of the three rubbers tested in this study. Furthermore, cryogenic rubber mixtures had the lowest values of strain at maximum stress.

Conclusions based upon the results of the field trial are as follows:

1. The field trial was successfully constructed and sufficiently documented for future monitoring.

2. The field trial materials had a diluent added to them which changed their properties considerably from the laboratory mixtures they were intended to duplicate.

3. With respect to mixing times, the field trial materials had compliance values which changed from high at the 0.25-hour mixing time to lower at the 1-hour mixing time to the highest at the 2.7-hour mixing time. The inverse of this was true for work, softening point, and viscosity values.

4. As curing time increased over 26 weeks, compliance values decreased, and softening point and viscosity values increased.

5. Correlations were established between compliance and softening point, and viscosity and softening point. These relationships had high coefficients of correlation.

6. A crack survey made 18 months after construction revealed the initiation of cracking in the field trial. Cracks occurring in one of the control sections are probably due to the passing of heavy fuel trucks. It is not certain whether cracks in the test sections are reflective.

The time-temperature study yielded the following conclusions:

1. As the test temperature increased the viscosity of the mixtures decreased and the compliance increased. The level of stress decreased as did the value of work energy with increasing test temperature. The level of strain at maximum stress was independent of the test temperature.

2. Viscosities of the asphalt-rubber mixtures at different test temperatures were mostly dependent upon the asphalt grades.

3. Mixtures made with the ambient-ground, tire-tread rubber were least dependent upon asphalt grade.

4. Compliance decreased with increasing sample deformation rates. The level of stress and work energy increased with increasing deformation rates. The level of strain at maximum stress for a given asphalt-rubber mixture was independent of the sample deformation rates.

5. Multiple linear regression of the stress-strain diagrams at different deformation rates and temperatures produced equations to predict stress at a given level of strain. These equations had excellent correlation coefficients and fair to good coefficients of variation.

RECOMMENDATIONS

1. Specifications have been developed based upon experience gained in this project as well as input from experts at Western Technologies, Inc., Sahuaro Asphalt and Petroleum Company, and International Surfacing, Inc. These guide specifications are in Appendix A.

2. The specifications in Appendix A are recipe-type guidelines. They are recommended only for the interim until end-product specifications can be developed. Asphalt-rubber producers are continually changing and improving their products. Nonjudicious use of the guide specifications may unnecessarily "lock" the technology.

3. The use of diluent in field mixtures should be avoided when it is possible to obtain the proper spraying viscosity without the diluent.

4. Future research efforts in asphalt-rubber should concentrate on the development of end-product specifications. The best way to accomplish this would be to test mixture properties at asphalt-rubber construction projects.

5. Further work should be done in developing correlations between elaborate laboratory test methods and simpler test methods that can be implemented in field construction.

6. A method for evaluating asphalt-rubber tensile behavior has been suggested. This method needs to be refined for application in design procedures. Work energy to fracture the material should also be incorporated into pavement design.

7. More research needs to be conducted on the mechanisms of reflection cracking in pavement overlays to quantify the stresses and strains occurring at interlayers.

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APPENDIX A

LABORATORY PROCEDURES FOR MIXING AND TESTING ASPHALT-RUBBER MIXTURES

This appendix describes the methods used to prepare and test asphalt-rubber mixtures for the laboratory portions of this study.

LABORATORY MIXING PROCEDURES

Apparatus

1. Mixing vessel--2000-ml, squat vessel with a body diameter of 5.5 inches, outer flange diameter of 8.6 inches, and an overall height of 7.1 inches. The vessel was made of heat-resistant glass and had a four-neck, ground seal cover.
2. Heating mantle--a 440-watt, 115-volt heater capable of completely surrounding the mixing vessel. It was a temperature probe-controlled unit with an asbestos lining.
3. Mixing vessel stand--a drill press stand for 0.5-inch electric drills anchored to the table top.
4. Stirrer--a stainless steel rod 10.5 inches long by 0.25 inches in diameter having a paddle 2.5 inches long by 2.5 inches in diameter.
5. Stirring motor--a constant speed, variable torque, direct-drive electrical motor.
6. Speed/Torque controller--to maintain a constant speed in the stirring motor while monitoring torque.

The mixing apparatus is shown in Figure A-1.

Procedure

1. Nine hundred grams of cold asphalt were weighed into the mixing vessel.
2. The mixing vessel was placed in the heating mantle and the asphalt was heated to the desired mixing temperature. The asphalt was stirred

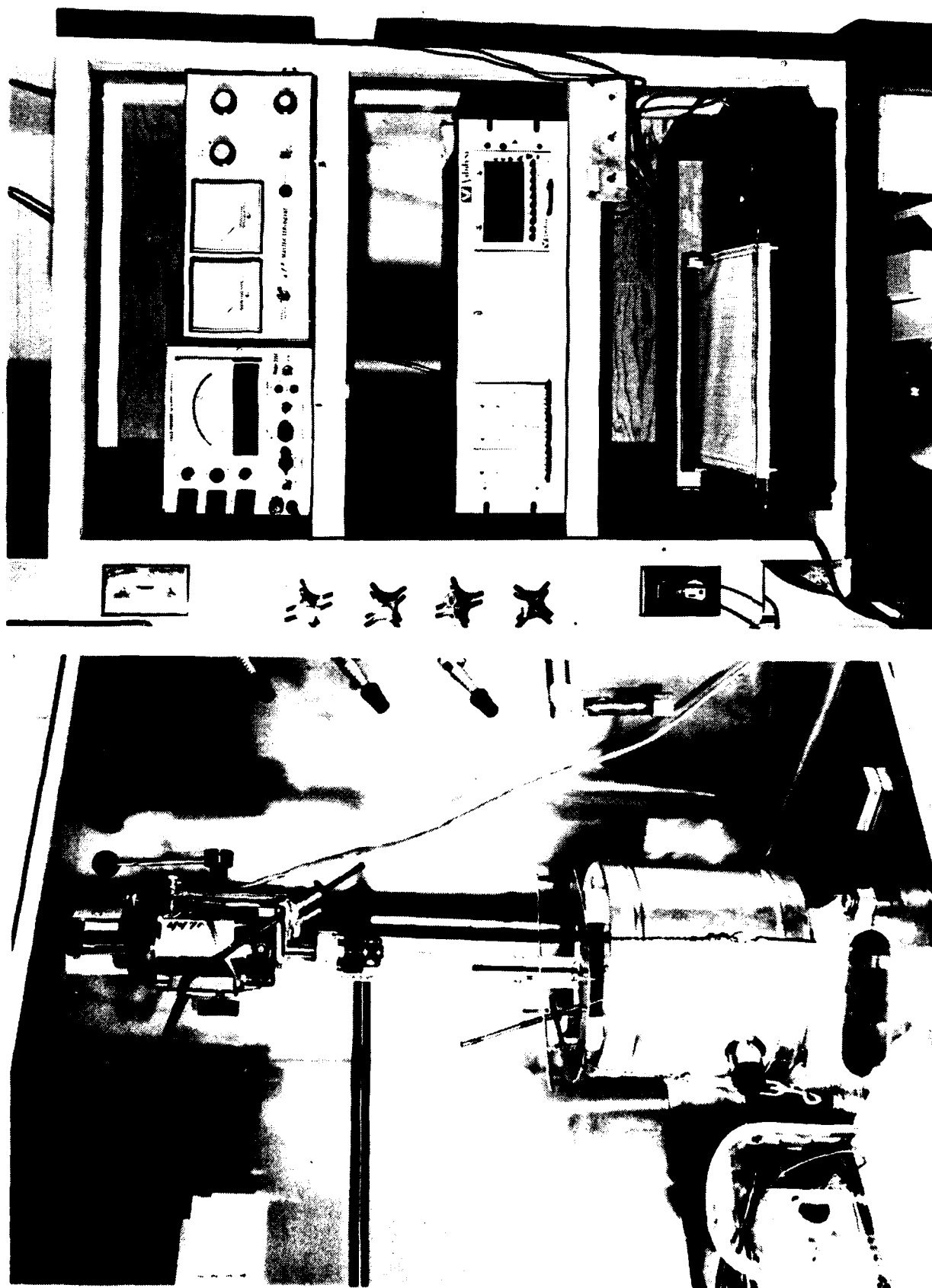


Figure A-1. Mixing Apparatus.

occasionally by hand until it was sufficiently fluid to pour. The stirring motor, with the stirrer, was started and the speed was adjusted to 500 rpm.

3. When the asphalt attained the desired mixing temperature, 300 grams of rubber were added.

4. The mixture was allowed to stabilize to the desired temperature and mixed for the desired mixing time. The mixing speed and temperature were checked and, if necessary, adjusted every 10 minutes.

5. The mixing vessel was removed from the heating mantle after the specified time and the mixture was transferred to 8-ounce cosmetic tins.

TESTING

Modified Softening Point Test

Apparatus

1. Mold--a two-piece brass mold conforming to the dimension shown in Figure A-2.
2. Balls--steel balls 0.375 inches in diameter, each weighing 3.50 ± 0.05 grams.
3. Bath--a 1000-ml low-form Griffin beaker of heat-resistant glass.
4. Glass tube--a piece of 9-mm glass tubing approximately 6 inches long.
5. Wooden dowel--a wooden dowel rod approximately 6 inches long and 0.25 inches in diameter.
6. Rubber bulb--squeeze bulb having 1- to 2-ounce capacity with a 0.25-inch opening.
7. Sample holder--an assembly conforming to the materials and dimensions shown in Figure A-3.
8. Thermometer--a thermometer conforming to the Thermometer 113°F or 113°C as specified in ASTM E1.

Reagents and Materials

All dimensions are in inches.

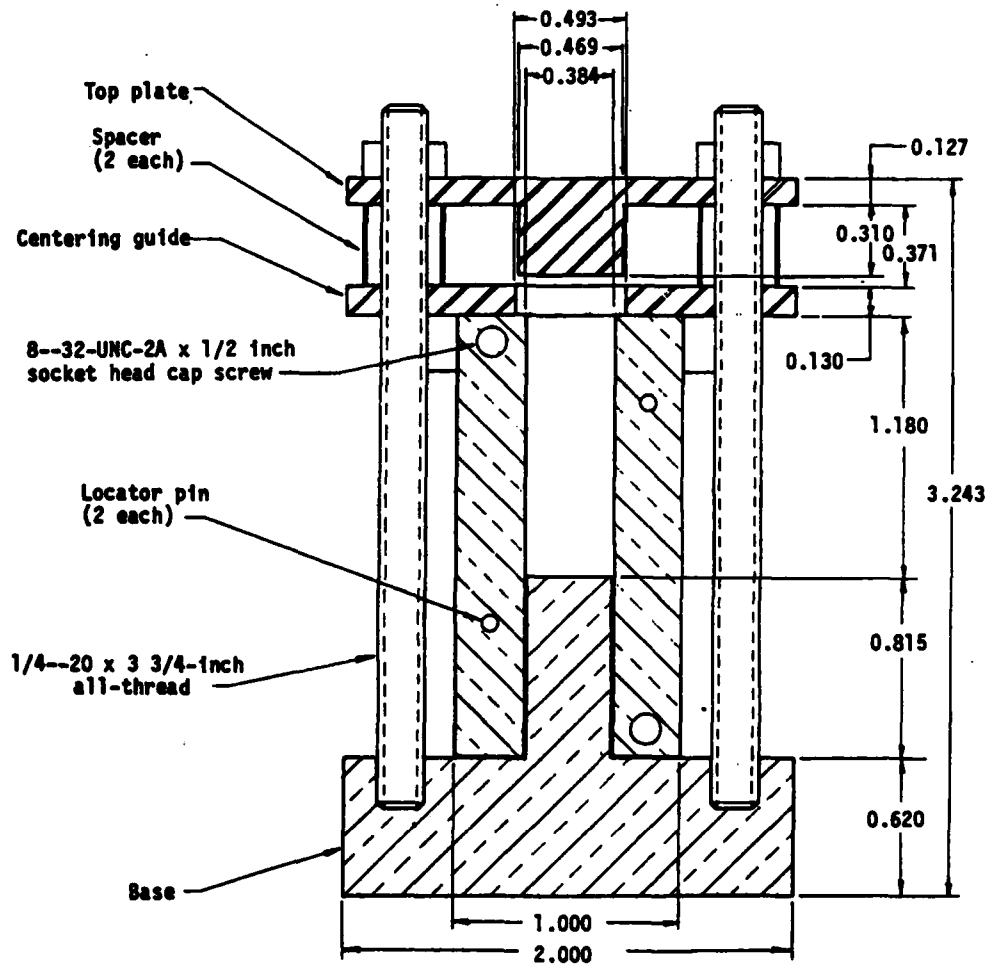


Figure A-2. Modified Softening Point Sample Mold.

All dimensions are in inches.

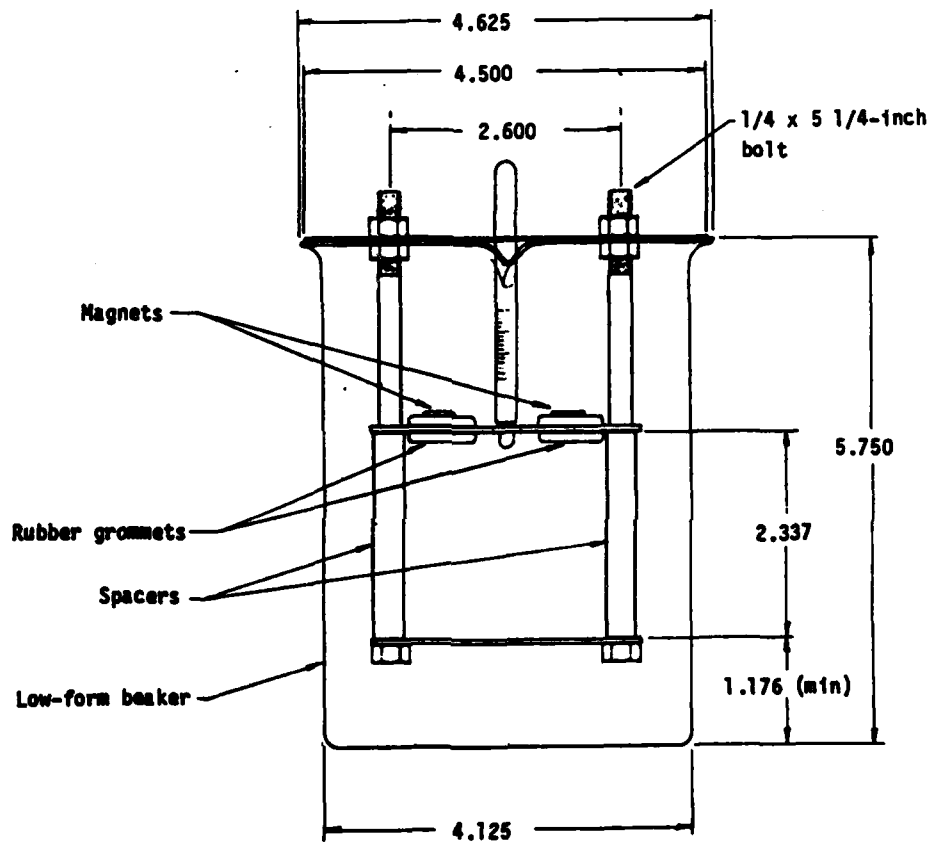


Figure A-3. Modified Softening Point Testing Apparatus.

1. Bath liquid--ethylene glycol with a boiling point between 383°F and 387°F.

CAUTION: Ethylene glycol is toxic when taken internally or when inhaled as a vapor. Conduct the test in a hood or other well-ventilated location. Avoid prolonged or repeated contacts with skin and inhalation of vapors.

Sample Preparation

1. The sample was stirred constantly during heating to prevent local overheating until it was sufficiently fluid to pour. Heating was limited to less than 325°F and 60 minutes.

2. The assembled mold was lined with one thickness of nonstick paper.

3. The squeeze bulb was placed over one end of the glass tube and the tube was gently heated over a flame.

NOTE: Steps C.4 through C.6 were completed in less than 60 seconds to keep the asphalt-rubber in a workable state.

4. The glass tube was inserted into the sample and a sufficient amount of asphalt-rubber was withdrawn to fill the mold.

5. A heated ball was placed into the mold. The squeeze bulb was removed from the end of the sample-filled tube. The sample was forced into the mold with the wooden dowel.

6. The other heated ball was placed on top of the molded sample. The top plate was placed on the assembly and the nuts were tightened.

7. The sample was allowed to cool for 5 minutes in the mold. Then the mold was disassembled and the sample removed. The nonstick paper surrounding the sample was taped and the sample was placed in the freezer for 30 minutes. The excess material around the balls was trimmed with a razor blade and the nonstick paper was removed from the sample.

8. The sample was placed in a 32°F ethylene glycol bath.

9. Not more than 240 minutes elapsed between the time of pouring the sample and the completion of the test.

Procedure

1. The fluid-filled apparatus was assembled in the laboratory hood with the sample suspended vertically from the magnets. The hood exhaust fan was operating during the entire test.
2. The bath was heated from below so that the temperature rose at a uniform rate of $9 \pm 1.0^\circ\text{F}$ per minute after the first 3 minutes.
3. The temperature was recorded at the instant the bottom ball, attached to the sample, touched the bottom plate.

Constant Pressure (Schweyer) Viscosity

References 25 and 26 describe the components and operation of the Schweyer Rheometer in detail. A summary of the modifications necessary for performing this test on asphalt rubber are presented here. These modifications are largely the results of work done by Jimenez (Reference 13).

Figure A-4 is a schematic of the Schweyer Rheometer as it was used in this study. Essentially, nitrogen gas is forced upon a piston which drives the plunger to push the sample through the tube. A pressure gage mounted on the front of the rheometer measures the gas pressure, and the displacement of the plunger is measured by means of a linear variable differential transducer (LVDT). The shear stress was calculated by the following equation:

$$\tau = \frac{F_p}{\pi D_s L_s} \quad (\text{A-1})$$

where

τ = shear stress
 F_p = force of the piston
 D_s = diameter of the tube
 L_s = length of the tube

The equation for shear rate was

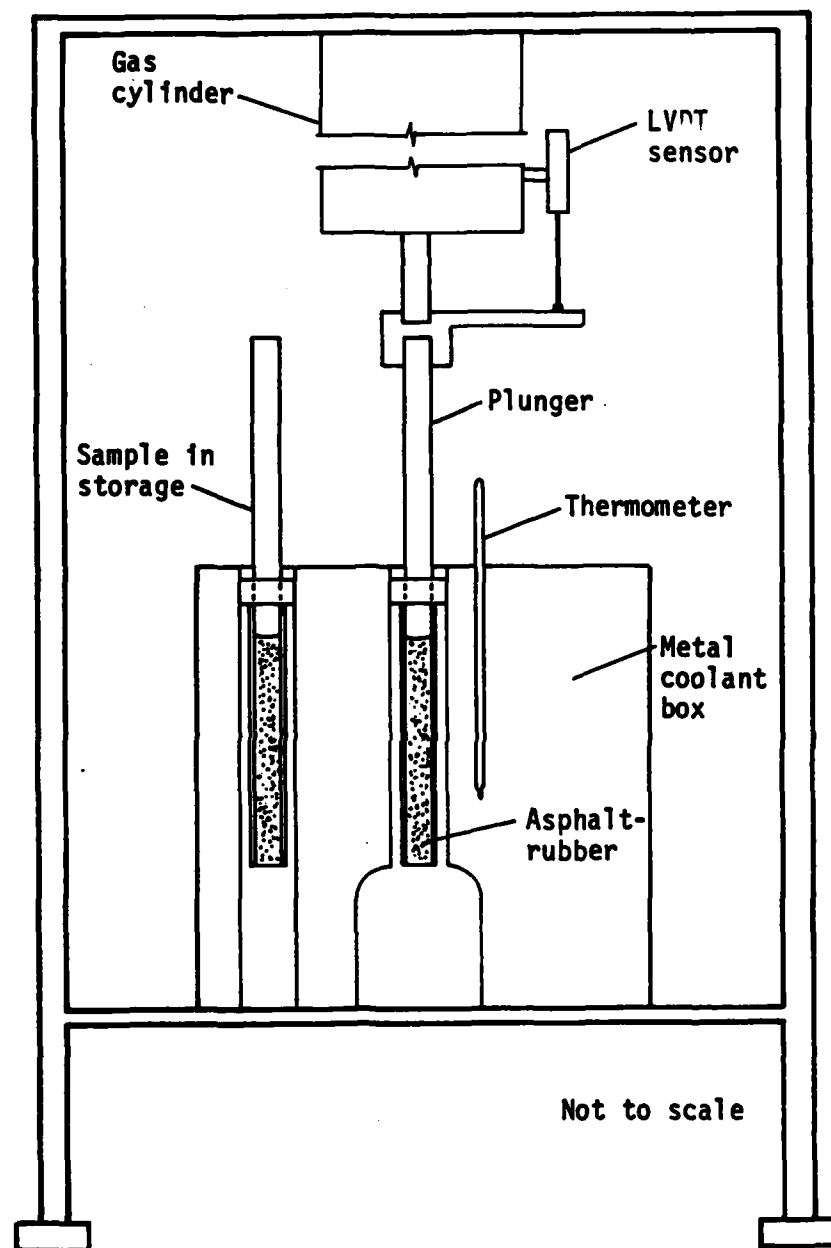


Figure A-4. Schweyer Rheometer Schematic.

$$\dot{\gamma} = \frac{8V_s}{D_s} \quad (A-2)$$

where

$\dot{\gamma}$ = shear rate
 V_s = velocity of the plunger
 D_s = diameter of the tube

The sample preparation closely followed the procedure outlined in Reference 13. However, in this study aluminum plugs were not used at the bottom of the tube and silicon grease was not applied to the plunger. The length of the sample was measured from the bottom of the tube. The diameter of the tubes used in this study was 0.375 inches.

Force Ductility

Apparatus

1. Mold--a brass mold of the same dimensions as shown in Figure A-5. The ends, A and A', are referred to as the clips.
2. Water bath--The water bath was maintained at the desired test temperature. The volume of water in the bath was approximately 2.5 gallons and the specimens were immersed to a depth of approximately 2.5 inches.
3. Testing machine--The tension device was oriented horizontally and capable of moving at speeds of 0.25, 1.0, and 5.0 cm/min. Load cells were mounted in the direction of the tension, in line with the samples. The load cells had a 25-pound capacity.
4. Chart recorder--The strip chart recorder had a time-based and a load-base axis.

Sample Preparation

1. The samples were stirred constantly during heating to prevent local overheating until they were sufficiently fluid to pour.

All dimensions are in inches.

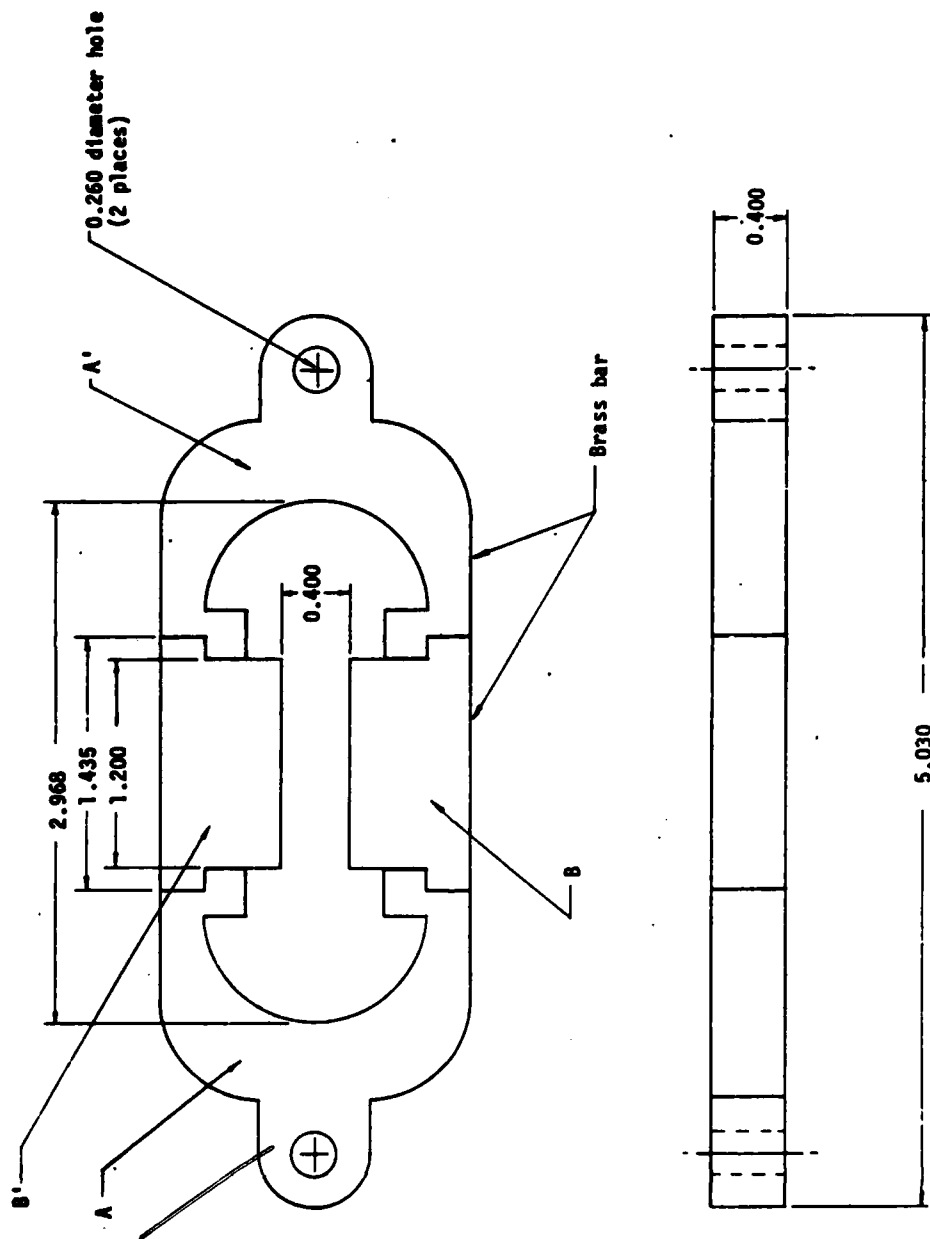


Figure A-5. Force-Ductility Mold.

2. The mold in Figure A-4 was assembled on a brass plate. The plate and model sides, B and B', were thoroughly coated with a mixture of glycerin and talc.

3. Care was taken in filling the mold not to disarrange the parts. It was necessary to tamp the material into the mold with a toothpick to ensure that there were no voids in the sample. The mold was slightly overfilled.

4. The sample was cooled at room temperature for a period of 30 to 40 minutes and then placed in a freezer for about 5 minutes.

5. The excess asphalt-rubber was then cut off with a hot spatula to make the mold just level full.

Testing Procedure

1. The brass plate with three molded samples was placed in the bath for a period of 30 minutes. The samples were then removed from the brass plate and the side pieces were detached from the samples.

2. One clip was attached to the machine crosshead and the other to a hook on the load cell. The chart recorder was turned on and the clips were pulled apart at the desired rate until the sample ruptured.

APPENDIX B
TABULAR SUMMARY OF TEST RESULTS

TABLE B-1. SUMMARY OF TENSILE PROPERTIES OF MATRIX I MIXTURES AT 39.2°F

Rubber Type	Mixing Temperature, °F	Maximum True Stress, psi		True Strain at Maximum True Stress, in/in		Compliance, 10 ⁻⁴ psi ⁻¹		Work, in-lb	
		Mean	n ^a SDb	Mean	n ^a SDb	Mean	n ^a SDb	Mean	n ^a SDb
TP044	325	292	18 31	1.32	18 0.08	48	18 5.6	38	18 4.5
	375	267	18 49	1.34	18 0.10	55	18 5.3	34	18 6.7
	425	255	18 39	1.49	18 0.08	70	18 6.9	33	18 6.0
C-104	325	255	18 29	1.20	18 0.11	47	18 2.4	36	18 7.8
	375	256	18 36	1.28	18 0.10	53	18 3.4	33	18 5.3
	425	199	18 24	1.39	18 0.07	74	17 5.9	27	17 3.8
APC-10	325	233	18 14	0.93	18 0.07	39	17 2.3	28	17 2.7
	375	254	18 26	1.15	18 0.10	44	18 2.8	34	18 4.8
	425	227	18 15	1.34	18 0.06	60	18 2.6	32	18 2.7

^aNumber of samples^bStandard deviation

Note: Other variables investigated in this experiment included storage period (1, 8, and 28 days) and storage condition (ambient and frozen). Storage period was noted to have significant effect ($\alpha = 0.05$) only upon true strain at maximum true stress and only at the 28-day period. Storage condition had a significant effect only upon compliance at $\alpha = 0.05$. However, these differences were found most likely due to test variability rather than the independent variables.

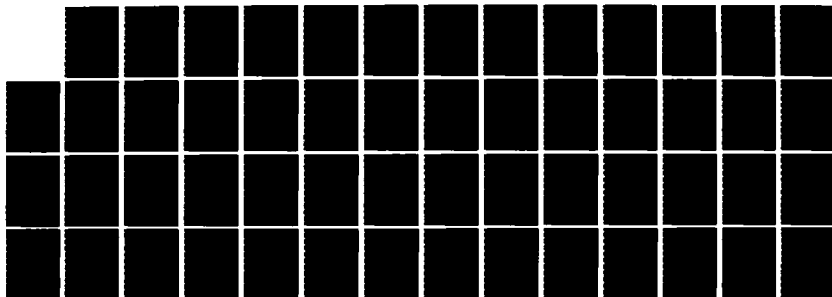
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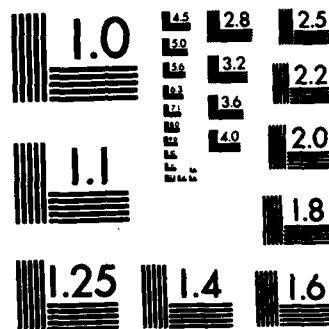
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TABLE B-2. SUMMARY OF FLOW PROPERTIES OF MATRIX I MIXTURE

Rubber Type	Mixing Temperature, °F	Modified Softening Point Temperature, °F			Log Viscosity at 0.05 s ⁻¹ and 60°F, $\frac{P}{P}$			Log Viscosity at 100 W/m ³ and 60°F, $\frac{P}{P}$			Complex Flow Parameter, $\frac{C}{C}$		
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	325	139	18	4.8	8.2371	12	0.0981	9.1933	12	0.0547	0.43	12	0.047
	375	150	18	2.9	8.1953	12	0.2393	9.2928	12	0.1923	0.37	12	0.076
	425	147	17	3.6	8.0095	12	0.1777	9.1234	12	0.1544	0.34	12	0.051
C-104	325	144	18	3.8	8.1393	12	0.1294	9.1819	12	0.0655	0.39	12	0.056
	375	148	18	3.3	8.2280	12	0.0838	9.3100	12	0.0642	0.39	12	0.033
	425	146	18	2.7	8.0471	12	0.0756	9.1277	12	0.0811	0.36	12	0.041
APC-10	325	140	18	3.4	8.2801	12	0.3053	9.2328	12	0.1200	0.42	12	0.076
	375	146	18	4.4	8.2697	12	0.1756	9.3277	12	0.0947	0.40	12	0.068
	425	143	18	3.2	8.1603	12	0.0761	9.1881	12	0.0430	0.40	12	0.029

^aNumber of samples

^bStandard deviation

Note: Other variables investigated in this experiment included storage period (1, 8, and 28 days) and storage condition (ambient and frozen). Storage condition had no significant effect upon any flow properties. Storage period had an effect after 28 days upon Schweyer viscosity values at $\alpha = 0.05$.

TABLE B-3. SUMMARY OF TENSILE PROPERTIES OF MATRIX II MIXTURES AT 39.2°F

Rubber Type	Mixing Time, hr	Rep	Maximum True Stress, psi		True Strain at Maximum True Stress, in/in		Compliance, 10 ⁻⁴ psi ⁻¹		Work, in-lb	
			Mean	n ^a SDb	Mean	n ^a SDb	Mean	n ^a SDb	Mean	n ^a SDb
TPD44	0.5	1	202	6 37	1.22	6 0.05	56	6 1.2	28	6 2.7
		2	246	6 52	1.25	6 0.18	53	6 1.5	31	6 8.1
	1.0	1	185	6 42	1.19	6 0.19	64	6 4.3	24	6 6.2
		2	229	6 28	1.25	6 0.10	54	6 1.6	31	6 4.6
	4.0	1	232	6 21	1.37	6 0.06	61	6 1.9	32	6 3.5
		2	190	6 38	1.38	6 0.11	75	6 5.9	26	6 5.2
C-104	0.5	1	178	6 31	1.05	6 0.19	53	6 2.0	23	6 6.5
		2	187	6 29	1.11	6 0.11	52	6 1.0	26	6 6.0
	1.0	1	206	6 50	1.15	6 0.13	55	6 6.2	26	6 7.5
		2	277	6 14	1.25	6 0.05	52	6 1.6	32	6 2.2
	4.0	1	216	6 11	1.26	6 0.02	56	6 1.7	30	6 1.9
		2	204	6 22	1.23	6 0.06	58	6 1.6	27	6 3.3
APC-10	0.5	1	174	6 41	0.70	6 0.22	37	6 3.6	17	6 7.0
		2	184	6 11	0.91	6 0.05	43	6 2.6	22	6 1.2
	1.0	1	211	6 38	0.92	6 0.14	41	6 1.8	24	6 6.0
		2	229	6 28	1.04	6 0.08	42	6 1.6	29	6 5.1
	4.0	1	215	6 37	1.12	6 0.13	50	6 2.3	28	6 7.6
		2	234	6 19	1.16	6 0.07	48	6 1.4	30	6 3.7

^aNumber of samples^bStandard Deviation

TABLE B-4. SUMMARY OF FLOW PROPERTIES OF MATRIX II MIXTURES

Rubber Type	Mixing Time, hr	Rep	Modified Softening Point Temperature, °F			Log Viscosity at 0.05 s ⁻¹ and 60°F.			Log Viscosity at 100 W/m ³ and 60°F.			Complex Flow Parameter, G		
			Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	0.5	1	150	6	5.1	8.4326	4	0.1295	9.4170	4	0.0327	0.48	4	0.061
		2	150	6	2.9	8.3338	4	0.0741	9.4471	4	0.1218	0.44	4	0.029
	1.0	1	152	6	1.8	8.3621	4	0.0526	9.5286	4	0.0438	0.42	4	0.019
		2	156	6	6.9	8.3677	4	0.0481	9.4403	4	0.0169	0.34	4	0.068
	4.0	1	155	6	1.5	8.1506	4	0.2585	9.3848	4	0.2069	0.41	4	0.029
		2	152	6	0.8	8.3522	4	0.0585	9.3900	4	0.0328	0.45	4	0.041
C-104	0.5	1	151	6	2.1	8.3636	4	0.1282	9.3605	4	0.0865	0.47	4	0.034
		2	148	6	3.5	8.4511	4	0.0348	9.3688	4	0.0460	0.47	4	0.028
	1.0	1	145	6	3.9	8.2970	4	0.0774	9.4870	4	0.0117	0.51	4	0.022
		2	147	6	3.5	8.3337	4	0.0297	9.3128	4	0.0355	0.42	4	0.027
	4.0	1	152	6	2.0	8.2890	4	0.0610	9.3776	4	0.0387	0.39	4	0.041
		2	150	6	2.4	8.3507	4	0.0253	9.4489	4	0.0151	0.43	4	0.010
APC-10	0.5	1	141	6	4.0	8.5219	4	0.0581	9.2712	4	0.0266	0.59	4	0.026
		2	143	6	6.3	8.5898	4	0.0830	9.5062	4	0.0437	0.51	4	0.052
	1.0	1	144	6	4.0	8.3837	4	0.0994	9.4437	4	0.0359	0.53	4	0.056
		2	160	6	1.0	8.5037	4	0.0362	9.4491	4	0.0933	0.43	4	0.030
	4.0	1	152	6	1.4	8.4755	4	0.1142	9.6130	4	0.0924	0.45	4	0.043
		2	152	6	1.7	8.5624	4	0.1152	9.4909	4	0.0223	0.52	4	0.007

^aNumber of samples

^bStandard Deviation

TABLE B-5. SUMMARY OF TENSILE PROPERTIES OF FIELD TRIAL MATERIAL AT 0 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi ⁻¹			Work, in-lb		
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	Control ^c 0.25	141	6	15	1.27	6	0.09	90	6	2.8	19	6	3.1
		49	6	8	1.39	6	0.09	253	6	24.3	9	6	1.2
	1.00	81	6	5	1.43	6	0.04	171	6	11.1	13	6	1.0
	2.70	5	6	2	0.91	6	0.21	2507	6	705.4	1	6	0.2
C-104	Control ^c 0.25	150	6	19	1.18	6	0.07	72	6	3.9	21	6	4.0
		30	6	2	1.17	6	0.08	351	6	30.2	5	6	0.3
	1.00	42	6	5	1.02	6	0.09	214	6	16.0	6	6	1.0
	2.70	19	6	6	1.23	6	0.05	629	6	139.4	3	6	1.0
CPR-10P	Control ^c 0.25	102	6	5	0.96	6	0.05	83	6	5.2	13	6	1.7
		27	6	3	0.81	6	0.08	298	6	34.5	4	6	0.9
	1.00	43	6	3	0.89	6	0.08	200	6	20.6	6	6	0.7
	2.70 ^d	--	--	--	--	--	--	--	--	--	--	--	--

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

^dNo test data because of diluent reducing viscosity excessively.

TABLE B-6. SUMMARY OF FLOW PROPERTIES OF FIELD TRIAL MATERIAL AT 0 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Modified Softening Point Temperature, °F			Log Viscosity at 0.05 s ⁻¹ and 60°F, P			Log Viscosity at 100 W/m ³ and 60°F, P			Complex Flow Parameter, C		
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	Control ^c	133	6	5.9	8.1273	4	0.0403	8.8056	4	0.0572	0.58	4	0.028
	0.25	118	6	1.7	7.5109	4	0.0472	8.1474	4	0.0190	0.50	4	0.035
	1.00	124	6	2.7	7.7280	4	0.0380	8.3736	4	0.0535	0.53	4	0.025
	2.70	95	6	2.8	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d
C-104	Control ^c	133	6	4.8	8.1454	4	0.0418	8.9357	4	0.0354	0.53	4	0.027
	0.25	114	6	3.3	7.3620	4	0.0278	8.0363	4	0.0115	0.45	4	0.029
	1.00	121	6	4.8	7.5193	4	0.0539	8.2154	4	0.0114	0.47	4	0.035
	2.70	113	6	2.5	7.2066	4	0.0330	7.9091	4	0.0486	0.39	4	0.029
CPR-10P	Control ^c	127	6	5.8	8.0732	4	0.0753	8.8225	4	0.0793	0.53	4	0.015
	0.25	116	6	1.8	7.4406	4	0.0634	8.1414	4	0.0319	0.45	4	0.034
	1.00	119	6	2.8	7.6103	4	0.2306	8.3625	4	0.0262	0.45	4	0.162
	2.70	81	6	1.8	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

^dValues could not be obtained.

TABLE B-7. SUMMARY OF TENSILE PROPERTIES OF FIELD TRIAL MATERIAL AT 2 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi ⁻¹			Work, in-lb		
		Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
TP044	Control ^c	124	6	22	1.20	6	0.10	93	6	7.4	17	6	3.8
	0.25	55	6	9	1.30	6	0.05	222	6	20.5	8	6	1.1
	1.00	73	6	15	1.24	6	0.15	170	6	14.6	10	6	2.5
	2.70	6	6	1	0.99	6	0.14	1776	6	278.5	1	6	0.4
C-104	Control ^c	128	6	11	1.05	6	0.08	76	6	2.8	19	6	6.3
	0.25	30	6	5	1.16	6	0.03	339	6	40.5	5	6	0.9
	1.00	34	6	5	1.04	6	0.10	268	6	36.3	5	6	0.7
	2.70	17	6	5	0.97	6	0.29	543	6	124.1	3	6	1.3
CPR-10P	Control ^c	102	6	4	0.94	6	0.07	81	6	3.9	13	6	1.4
	0.25	33	6	4	0.78	6	0.07	247	6	24.8	5	6	1.1
	1.00	56	6	8	0.97	6	0.08	160	6	25.9	8	6	1.3
	2.70	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

^dValues could not be obtained.

TABLE B-8. SUMMARY OF FLOW PROPERTIES OF FIELD TRIAL MATERIAL AT 2 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Modified Softening Point Temperature, °F		Log Viscosity at 0.05 s ⁻¹ and 60°F _p		Log Viscosity at 100 W/m ³ and 60°F _p		Complex Flow Parameter, C	
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a
TP044	Control ^c	130	6	1.5	8.1657	4	0.1661	0.57	4
	0.25	119	6	2.0	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d
	1.00	123	6	2.7	7.9129	4	0.0841	0.64	4
C-104	2.70	98	6	2.9	7.0472	4	0.0112	0.34	4
	Control ^c	131	6	2.5	8.0644	4	0.2011	0.48	4
	0.25	109	6	3.8	7.4173	4	0.0397	0.47	4
CPR-10P	1.00	121	6	2.6	7.7297	3	0.0531	0.54	4
	2.70	114	6	2.7	7.2798	4	0.0458	0.44	4
	Control ^c	129	6	3.9	8.0952	4	0.0970	0.54	4
	0.25	116	6	3.2	7.4975	4	0.0615	0.45	4
	1.00	122	6	3.2	7.8183	4	0.0879	0.57	4
	2.70	84	6	5.7	-- ^d	-- ^d	-- ^d	-- ^d	-- ^d

^aNumber of samples

^bStandard deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

^dValues could not be obtained.

TABLE B-9. SUMMARY OF TENSILE PROPERTIES OF FIELD TRIAL MATERIAL AT 8 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi ⁻¹			Work, in-lb		
		Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
TP044	Control ^c	100	6	12	0.92	6	0.12	82	6	4.4	13	6	2.9
	0.25	47	6	8	1.16	6	0.18	217	6	9.7	7	6	2.0
	1.00	97	6	9	1.40	6	0.08	141	6	6.3	15	6	1.7
	2.70	8	6	2	1.01	6	0.18	1480	6	550.6	1	6	0.4
C-104	Control ^c	150	6	17	1.13	6	0.09	71	6	3.8	20	6	3.4
	0.25	41	6	4	1.13	6	0.13	238	6	20.8	7	6	1.0
	1.00	46	6	5	1.00	6	0.11	186	6	12.1	6	6	1.1
	2.70	24	6	4	1.11	6	0.12	407	6	67.9	4	6	0.7
CPR-10P	Control ^c	137	6	9	1.26	6	0.04	90	6	4.2	19	6	1.4
	0.25	60	6	15	0.91	6	0.14	134	6	22.7	8	6	2.7
	1.00	47	6	4	0.83	6	0.05	150	6	18.3	6	6	0.5
	2.70	9	6	1	0.78	6	0.09	1073	6	526.9	1	6	0.2

^aNumber of samples^bStandard Deviation^cControl material sampled from distributor trucks prior to addition of diluent.

TABLE B-10. SUMMARY OF FLOW PROPERTIES OF FIELD TRIAL MATERIAL AT 8 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Modified Softening Point Temperature, °F			Log Viscosity at 0.05 s ⁻¹ and 60°F.			Log Viscosity at 100 W/m ³ and 60°F.			Complex Flow Parameter,		
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	Control ^c	138	6	5.4	8.2122	4	0.0638	8.8613	4	0.0083	0.60	4	0.036
	0.25	119	6	4.0	7.7379	4	0.0392	8.3441	4	0.0300	0.56	4	0.023
	1.00	127	6	2.3	7.9936	4	0.1086	8.5627	4	0.0571	0.62	4	0.084
	2.70	107	6	3.4	7.1177	4	0.0376	7.8560	4	0.0390	0.34	4	0.016
C-104	Control ^c	142	6	3.2	8.2189	4	0.0767	9.0444	4	0.0320	0.52	4	0.039
	0.25	117	6	3.6	7.6655	4	0.1160	8.2650	4	0.0624	0.55	4	0.054
	1.00	128	6	1.3	7.7787	4	0.0530	8.4453	4	0.0291	0.53	4	0.033
	2.70	118	6	1.5	7.4220	4	0.0656	8.1100	4	0.0735	0.45	4	0.025
CPR-10P	Control ^c	133	6	4.6	8.1975	4	0.0793	8.9072	4	0.0212	0.57	4	0.043
	0.25	121	6	3.2	7.7466	4	0.0653	8.4858	4	0.1068	0.49	4	0.016
	1.00	128	6	2.6	7.7829	4	0.0990	8.4740	4	0.0153	0.52	4	0.068
	2.70	101	6	2.5	7.1577	4	0.0585	7.8808	4	0.0586	0.37	4	0.019

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

TABLE B-11. SUMMARY OF TENSELE PROPERTIES OF FIELD TRIAL MATERIAL AT 26 WEEKS CURING TIME

Rubber Type	Mixing Time, hr	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi-l			Work, in-lb		
		Mean	n	SD	Mean	n	SD	Mean	n	SD	Mean	n	SD
TP044	Control ^c	123	6	18	0.95	6	0.09	68	6	5.5	16	6	3.8
	0.25	76	6	23	1.14	6	0.11	134	6	20.7	11	6	3.9
	1.00	100	6	12	1.25	6	0.12	118	6	12.6	14	6	1.6
	2.70	42	6	5	1.39	6	0.10	298	6	58.5	7	6	1.3
C-104	Control ^c	117	6	34	0.93	6	0.24	74	6	5.2	14	6	6.0
	0.25	65	6	8	1.12	6	0.07	150	6	20.2	10	6	0.8
	1.00	83	6	9	1.09	6	0.06	119	6	14.4	11	6	1.7
	2.70	35	6	9	1.13	6	0.16	304	6	77.7	5	6	1.7
CPR-10P	Control ^c	150	6	27	1.23	6	0.11	82	6	5.6	20	6	3.9
	0.25	91	6	14	1.01	6	0.10	99	6	11.7	13	6	1.8
	1.00	83	6	6	0.94	6	0.06	98	6	10.5	11	6	0.7
	2.70	25	6	5	0.95	6	0.16	384	6	96.3	4	6	0.8

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

TABLE B-12. SUMMARY OF FLOW PROPERTIES OF FIELD TRIAL MATERIAL AT 26 WEEKS CURING TIME.

Rubber Type	Mixing Time, hr	Modified Softening Point Temperature, °F			Log Viscosity at 0.05 s ⁻¹ and 60°F.			Log Viscosity at 100 W/m ³ and 60°F.			Complex Flow Parameter, C		
		Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	Control ^c	140	6	3.5	8.3097	4	0.0647	9.0121	4	0.0658	0.59	4	0.015
	0.25	130	6	2.9	7.9354	4	0.0431	8.4751	4	0.0830	0.62	4	0.022
	1.00	131	6	2.6	8.1186	4	0.0578	8.7345	4	0.0171	0.61	4	0.030
	2.70	117	6	1.6	7.1957	4	0.0571	7.7663	4	0.0736	0.47	4	0.064
C-104	Control ^c	144	6	3.6	8.1918	4	0.3032	8.8951	4	0.1226	0.57	4	0.141
	0.25	128	6	1.5	7.8739	4	0.0751	8.4780	4	0.0751	0.58	4	0.121
	1.00	133	6	2.1	8.0051	4	0.0592	8.6411	4	0.0263	0.58	4	0.052
	2.70	125	6	4.1	7.8701	4	0.1576	8.3359	4	0.0247	0.66	4	0.112
CPR-10P	Control ^c	139	6	2.6	8.2535	4	0.0531	8.9181	4	0.0661	0.60	4	0.039
	0.25	126	6	2.9	8.0274	4	0.0466	8.6351	4	0.0466	0.60	4	0.014
	1.00	136	6	3.4	8.1812	4	0.0882	8.7682	4	0.0452	0.63	4	0.056
	2.70	122	6	3.3	7.4136	4	0.0836	8.0018	4	0.0542	0.51	4	0.046

^aNumber of samples

^bStandard Deviation

^cControl material sampled from distributor trucks prior to addition of diluent.

TABLE B-13. SUMMARY OF TENSILE PROPERTIES OF MATRIX III MIXTURES

Rubber Type	Asphalt Grade	Test Temperature, °F	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi ⁻¹			Work, in-lb		
			Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	AC5	80	5	6	2	1.07	6	0.28	2991	6	1977.9	1	6	0.3
		55	58	6	8	1.41	6	0.09	260	6	28.8	8	6	1.6
		30	339	6	44	1.40	6	0.06	49	6	2.9	40	6	5.4
	AC10	80	7	6	3	1.13	6	0.14	1692	6	939.1	1	6	0.6
		55	62	6	9	1.21	6	0.11	188	6	8.0	8	6	1.9
		30	304	6	54	1.25	6	0.12	43	6	2.4	38	6	6.8
	AC20	80	12	6	4	1.11	6	0.18	932	6	246.7	2	6	0.7
		55	109	6	17	1.31	6	0.07	128	6	21.7	14	6	2.6
		30	200	6	44	1.08	6	0.13	40	6	5.1	32	6	6.8
C-104	AC5	80	2	6	1	1.21	6	0.22	6013	6	2193.6	0.3	6	0.2
		55	32	6	10	1.34	6	0.12	434	6	161.0	5	6	1.7
		30	235	6	38	1.34	6	0.08	63	6	5.6	30	6	5.2
	AC10	80	5	6	3	1.17	6	0.18	2457	6	1517.1	1	6	0.5
		55	54	6	5	1.14	6	0.07	189	6	14.8	7	6	1.0
		30	233	6	30	1.19	6	0.11	51	6	9.5	30	6	4.8
	AC20	80	7	6	3	1.19	6	0.15	1676	6	757.5	1	6	0.5
		55	72	6	6	1.16	6	0.13	145	6	12.9	9	6	1.5
		30	298	6	49	1.12	6	0.14	36	6	2.7	38	6	9.3
APC-10	AC5	80	2	6	0.5	0.72	6	0.44	5047	6	2071.2	0.4	6	0.2
		55	47	6	4	1.15	6	0.12	232	6	31.1	6	6	0.6
		30	263	6	29	1.14	6	0.08	44	6	3.3	32	6	4.6
	AC10	80	5	6	1	0.94	6	0.19	2122	6	850.2	1	6	0.3
		55	64	6	7	1.07	6	0.14	153	6	18.7	8	6	1.6
		30	292	6	17	1.13	6	0.06	37	6	2.5	37	6	2.6
	AC20	80	12	6	3	0.95	6	0.19	870	6	168.6	2	6	0.4
		55	86	6	14	1.03	6	0.09	105	6	10.1	11	6	2.7
		30	300	6	15	1.00	6	0.07	31	6	1.0	36	6	3.2

^aNumber of samples^bStandard Deviation

TABLE B-14. SUMMARY OF FLOW PROPERTIES OF MATRIX III MIXTURES

Rubber Type	Asphalt Grade	Test Temperature °F	Log Viscosity at 0.05 s ⁻¹ and 60°F,			Log Viscosity at 100 W/m ³ and 60°F,			Complex Flow Parameter,		
			Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	AC5	80	7.6475	4	0.1299	8.1010	4	0.0710	0.63	4	0.068
		55	8.2914	4	0.1140	9.1651	4	0.0415	0.51	4	0.067
		30	9.3327	4	0.0982	10.6889	4	0.1057	0.47	4	0.062
	AC10	80	7.7453	4	0.1326	8.2655	4	0.0442	0.61	4	0.086
		55	8.4932	4	0.0628	9.4326	4	0.0910	0.51	4	0.057
		30	9.2445	4	0.0846	10.9643	4	0.0116	0.36	4	0.031
	AC20	80	8.0219	4	0.0711	8.4928	4	0.0494	0.68	4	0.021
		55	8.5981	4	0.0995	9.7643	4	0.0265	0.44	4	0.054
		30	9.5061	4	0.0357	11.1156	4	0.0434	0.42	4	0.022
C-104	AC5	80	7.3790	4	0.0802	7.8231	4	0.0871	0.61	4	0.136
		55	8.5609	4	0.1758	9.0063	4	0.0944	0.74	4	0.142
		30	9.2594	4	0.1078	10.6822	4	0.0761	0.44	4	0.061
	AC10	80	7.6719	4	0.0536	8.2627	4	0.0722	0.56	4	0.051
		55	8.4886	4	0.1744	9.3071	4	0.0223	0.56	4	0.094
		30	9.4772	4	0.1687	10.7353	4	0.0717	0.51	4	0.087
	AC20	80	7.8551	4	0.0299	8.3424	4	0.0000	0.64	4	0.020
		55	8.8284	4	0.0865	9.5802	4	0.0471	0.52	4	0.053
		30	9.6559	4	0.1894	10.9926	4	0.0878	0.50	4	0.096
APC-10	AC5	80	7.3131	4	0.1018	7.8556	4	0.0729	0.52	4	0.053
		55	8.6375	4	0.2484	9.0136	4	0.0876	0.78	4	0.186
		30	9.4397	4	0.1118	10.7035	4	0.0515	0.50	4	0.057
	AC10	80	7.6237	4	0.2951	8.1129	4	0.1485	0.60	4	0.160
		55	8.5857	4	0.0037	9.4787	4	0.0171	0.54	4	0.008
		30	9.4778	4	0.0466	10.7780	4	0.0723	0.50	4	0.030
	AC20	80	7.9892	4	0.1539	8.3493	4	0.0573	0.74	4	0.097
		55	8.8154	4	0.0540	9.6450	4	0.0471	0.59	4	0.037
		30	9.6053	4	0.0756	11.0769	4	0.0515	0.46	4	0.032

^aNumber of Samples
^bStandard Deviation

TABLE B-15. SUMMARY OF TENSILE PROPERTIES OF MATRIX IV MIXTURES

Rubber Type	Asphalt Grade	Deformation Rate, in/min	Maximum True Stress, psi			True Strain at Maximum True Stress, in/in			Compliance, 10 ⁻⁴ psi			Work, in-lb		
			Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b	Mean	n ^a	SD ^b
TP044	AC5	1.61	406	2	20	1.57	2	0.00	40	2	1.4	51	2	4.4
		0.32	255	2	12	1.59	2	0.02	65	2	2.1	33	2	2.9
		0.08	132	2	5	1.53	2	0.02	118	2	2.1	17	2	0.6
	AC10	1.61	318	2	20	1.35	2	0.05	44	2	0.7	43	2	2.8
		0.32	183	2	29	1.36	2	0.12	75	2	5.7	24	2	4.1
		0.08	111	2	22	1.27	2	0.13	115	2	6.4	15	2	3.7
	AC20	1.61	351	2	35	1.31	2	0.10	39	2	0.7	48	2	6.2
		0.32	218	2	26	1.29	2	0.09	60	2	2.8	28	2	4.1
		0.08	141	2	19	1.25	2	0.09	89	2	2.1	19	2	3.6
C-104	AC5	1.61	335	2	27	1.48	2	0.04	46	2	2.1	46	2	4.2
		0.32	180	2	6	1.48	2	0.02	83	2	2.8	24	2	0.3
		0.08	87	2	9	1.37	2	0.004	152	2	7.8	14	2	1.4
	AC10	1.61	242	2	19	1.16	2	0.00	37	2	0.0	35	2	2.6
		0.32	172	2	1	1.29	2	0.03	73	2	0.7	25	2	2.6
		0.08	82	2	12	1.16	2	0.08	120	2	0.0	12	2	2.1
	AC20	1.61	341	2	3	1.31	2	0.00	39	2	1.4	49	2	0.9
		0.32	178	2	31	1.09	2	0.17	61	2	0.7	23	2	5.8
		0.08	141	2	0.3	1.26	2	0.04	85	2	2.8	20	2	0.6
APC-10	AC5	1.61	324	2	26	1.31	2	0.10	41	2	0.0	44	2	4.2
		0.32	187	2	16	1.31	2	0.04	72	2	4.2	25	2	1.9
		0.08	92	2	6	1.23	2	0.02	132	2	5.7	12	2	0.7
	AC10	1.61	304	2	12	1.28	2	0.05	37	2	1.4	46	2	5.2
		0.32	168	2	5	1.10	2	0.08	61	2	1.4	23	2	2.0
		0.08	100	2	12	1.05	2	0.11	92	2	0.0	13	2	2.0
	AC20	1.61	322	2	9	1.07	2	0.00	29	2	1.4	44	2	1.7
		0.32	180	2	20	0.88	2	0.13	46	2	0.7	21	2	3.3
		0.08	128	2	1	0.98	2	0.05	67	2	0.0	17	2	0.8

^a Number of samples

^b Standard Deviation

APPENDIX C

STRESS-STRAIN DIAGRAMS FOR ALL
MATERIALS USED IN THIS STUDY

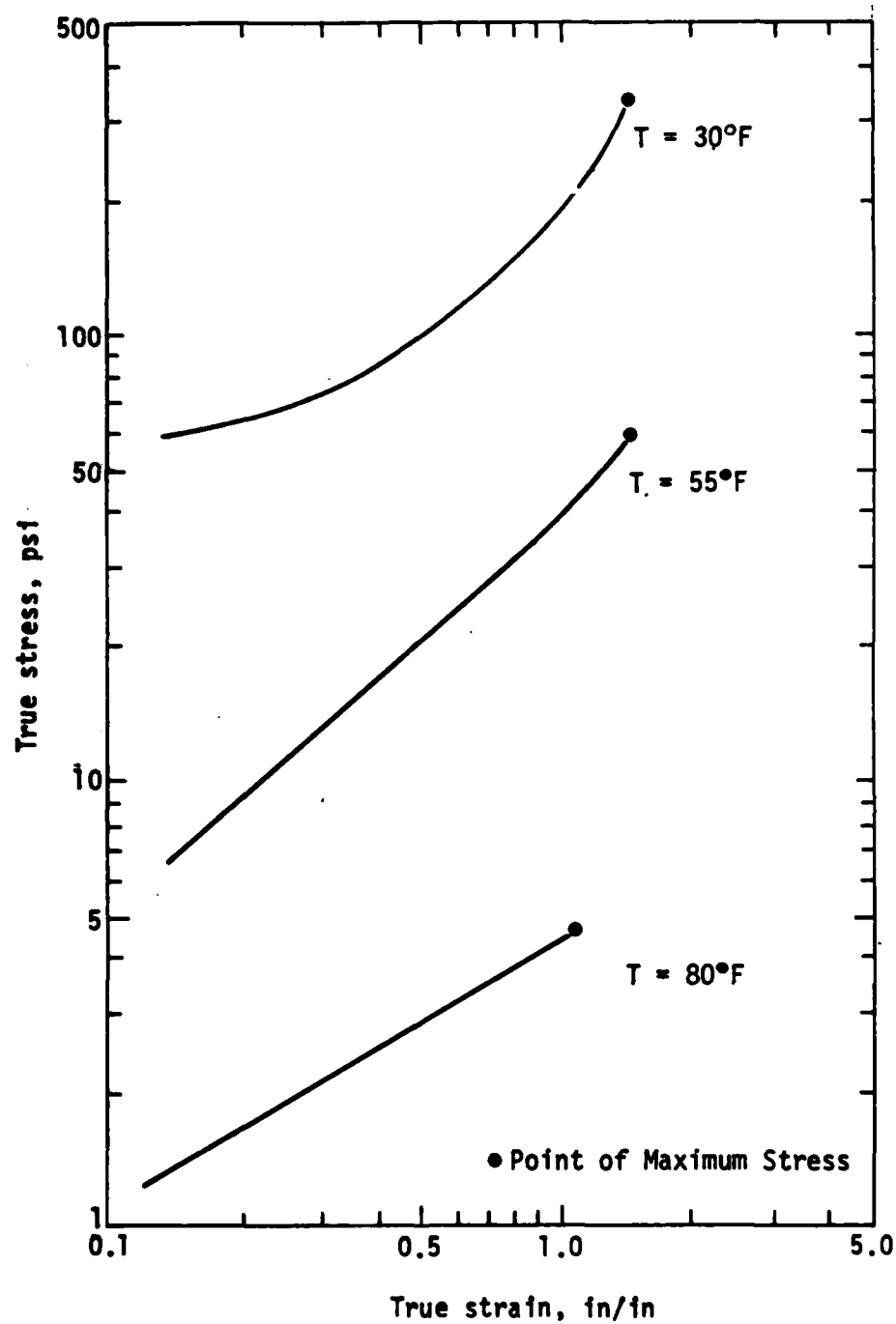


Figure C-1. Stress-Strain Curves for TP044, AC-5 at Different Temperatures and a Deformation Rate of 0.32 in/min.

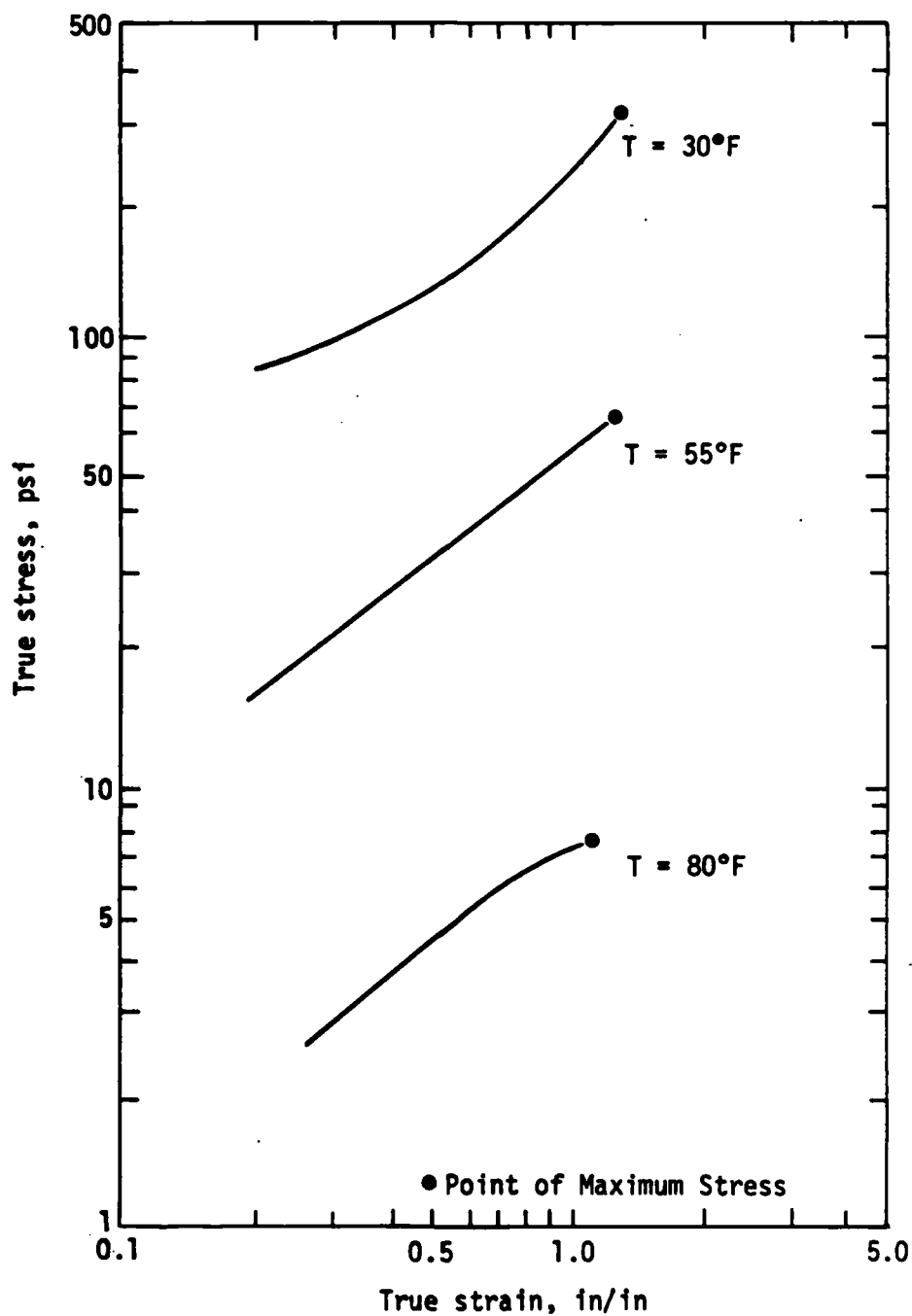


Figure C-2. Stress-Strain Curves for TP044, AC-10 at Different Temperatures and a Deformation Rate of 0.32 in/min.

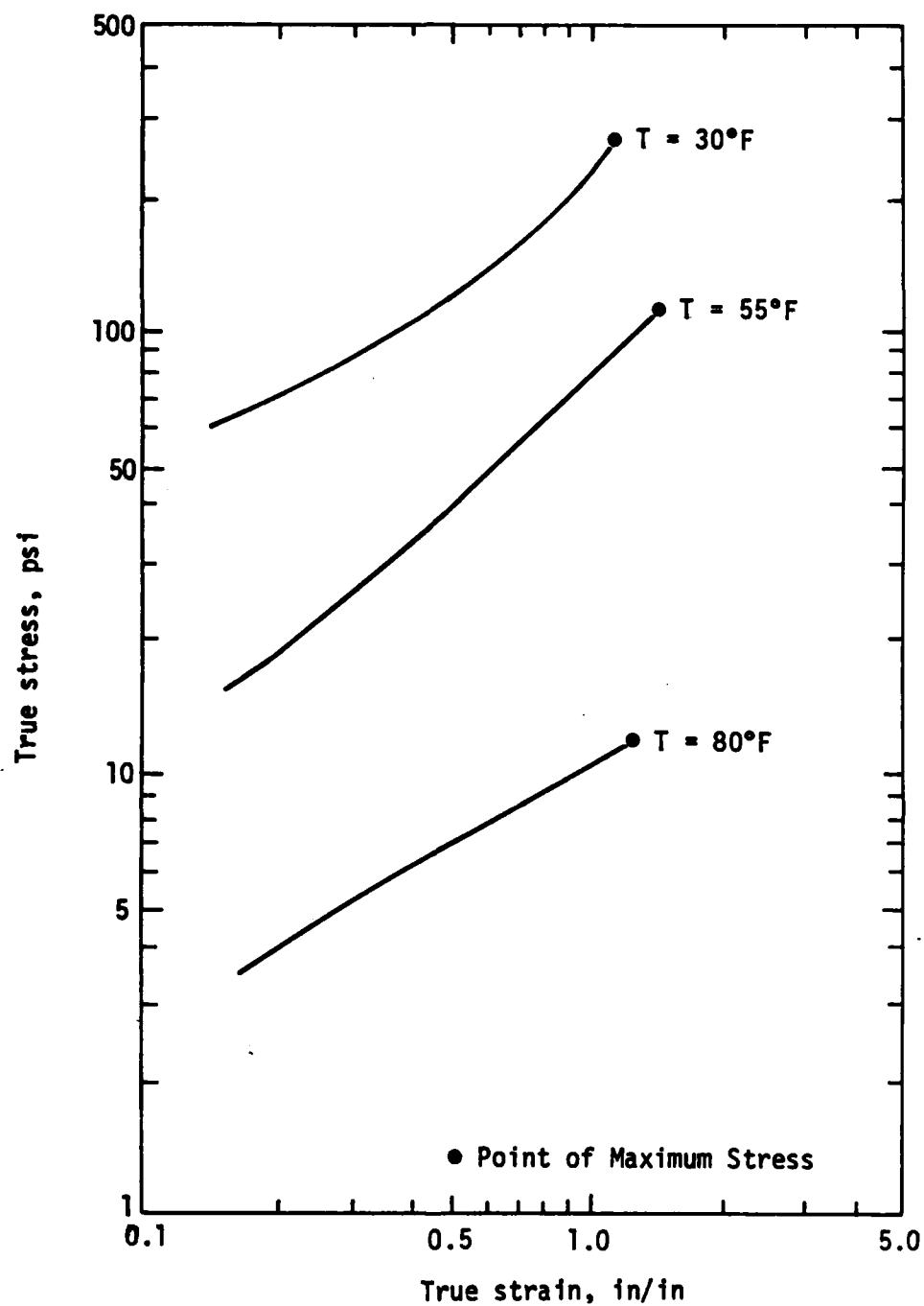


Figure C-3. Stress-Strain Curves for TP044, AC-20 at Different Temperatures and a Deformation Rate of 0.32 in/min.

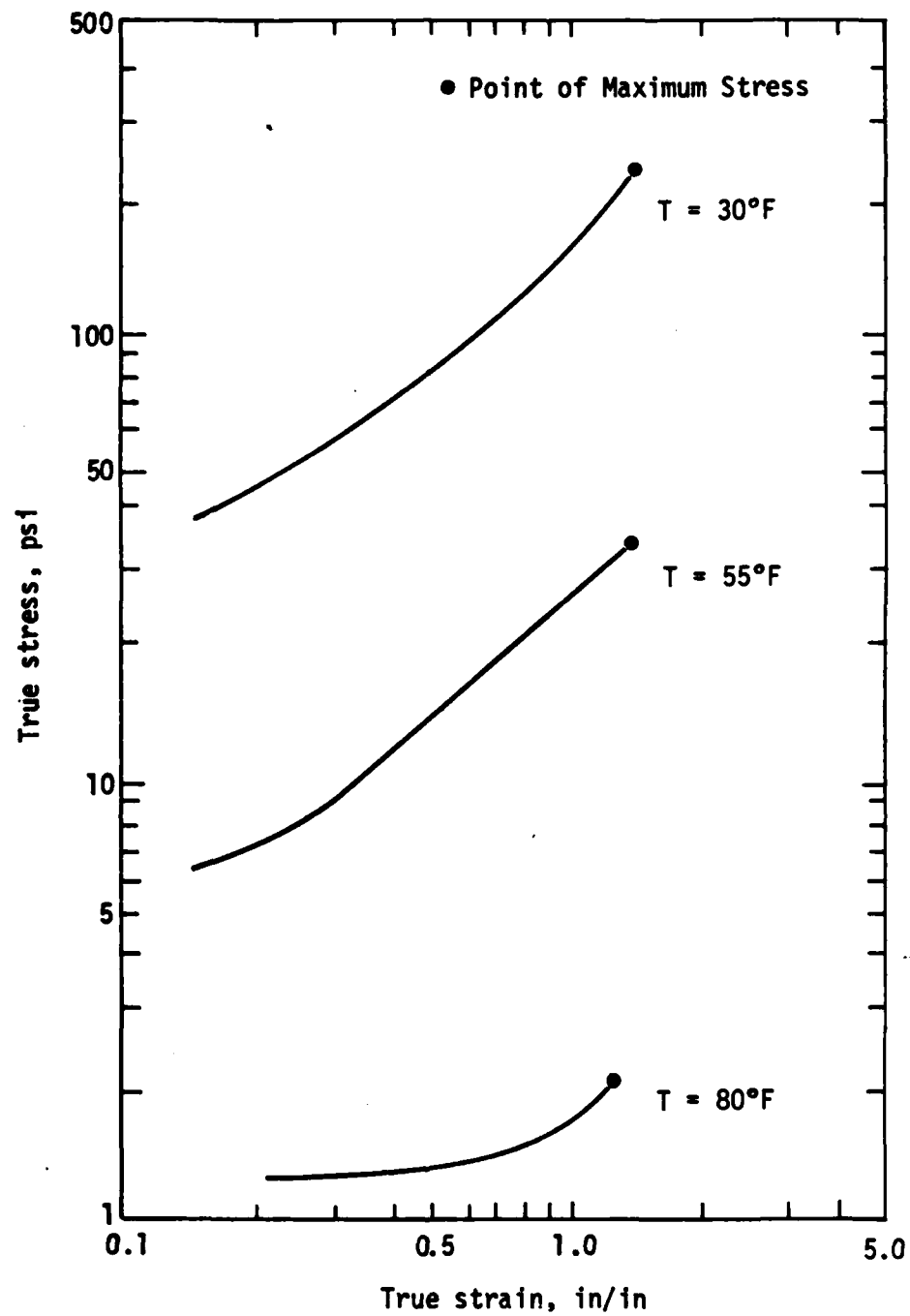


Figure C-4. Stress-Strain Curves for C-104, AC-5 at Different Temperatures and a Deformation Rate of 0.32 in/min.

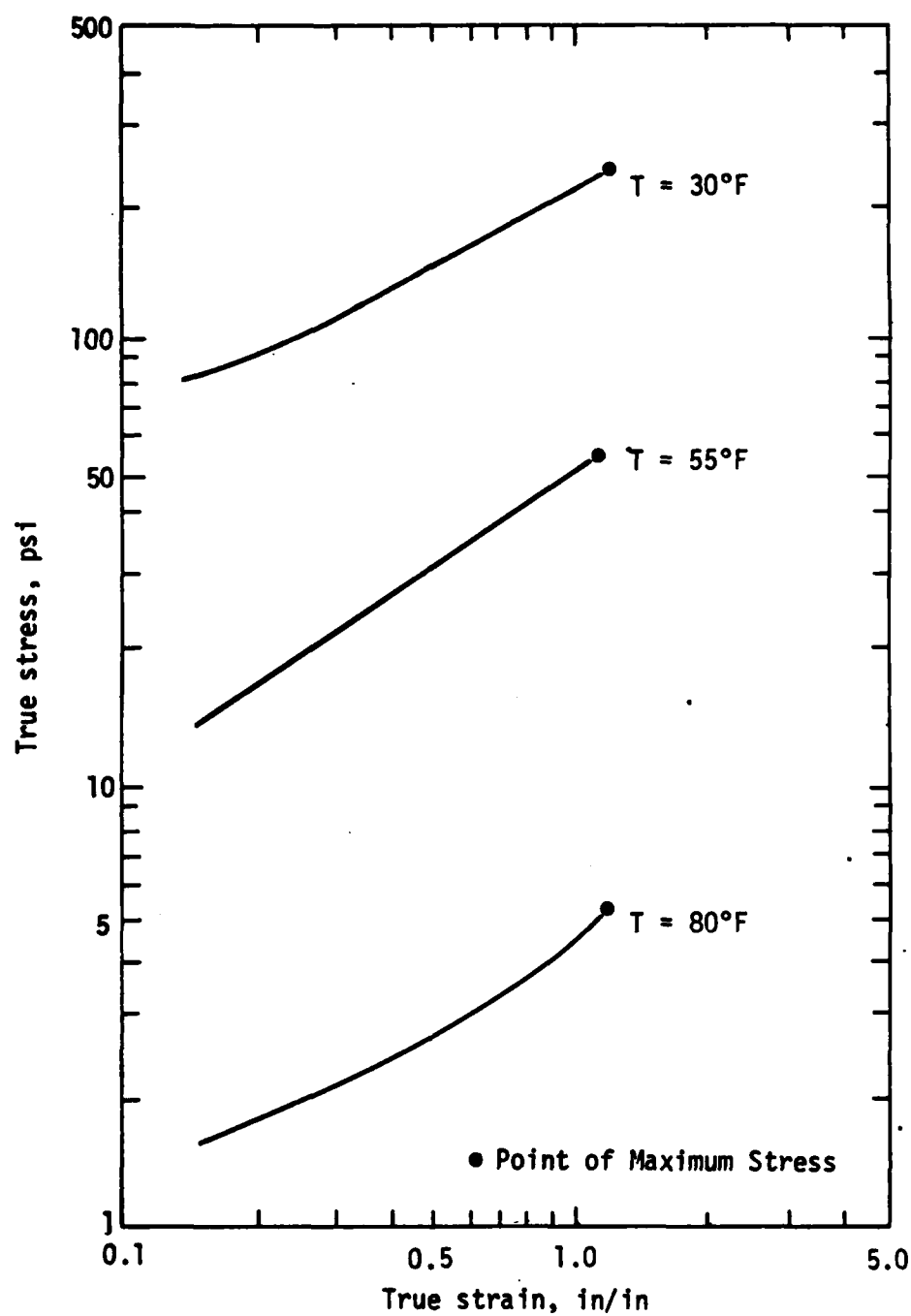


Figure C-5. Stress-Strain Curves for C-104, AC-10 at Different Temperatures and a Deformation Rate of 0.32 in/min.

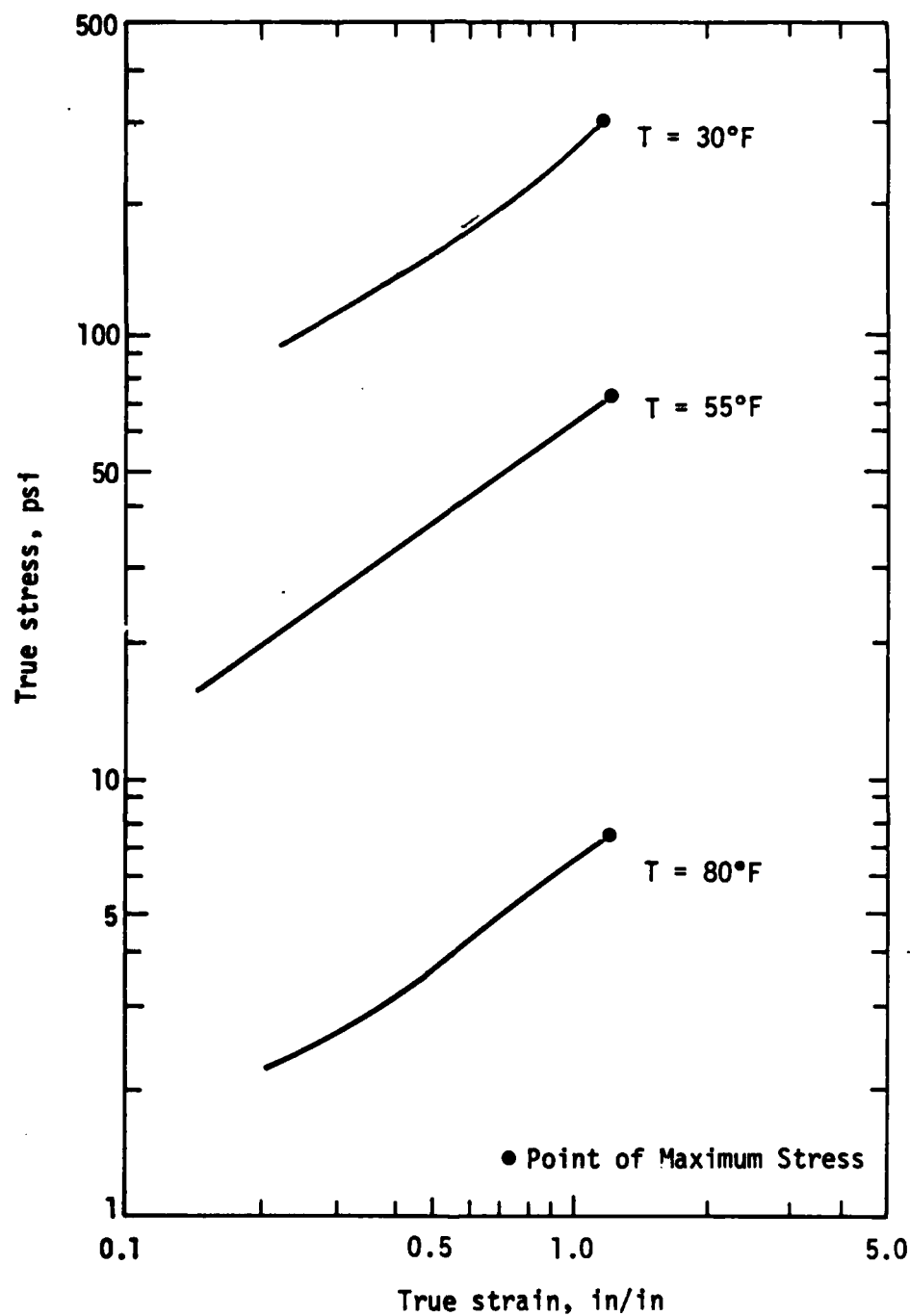


Figure C-6. Stress-Strain Curves for C-104, AC-20 at Different Temperatures and a Deformation Rate of 0.32 of in/min.

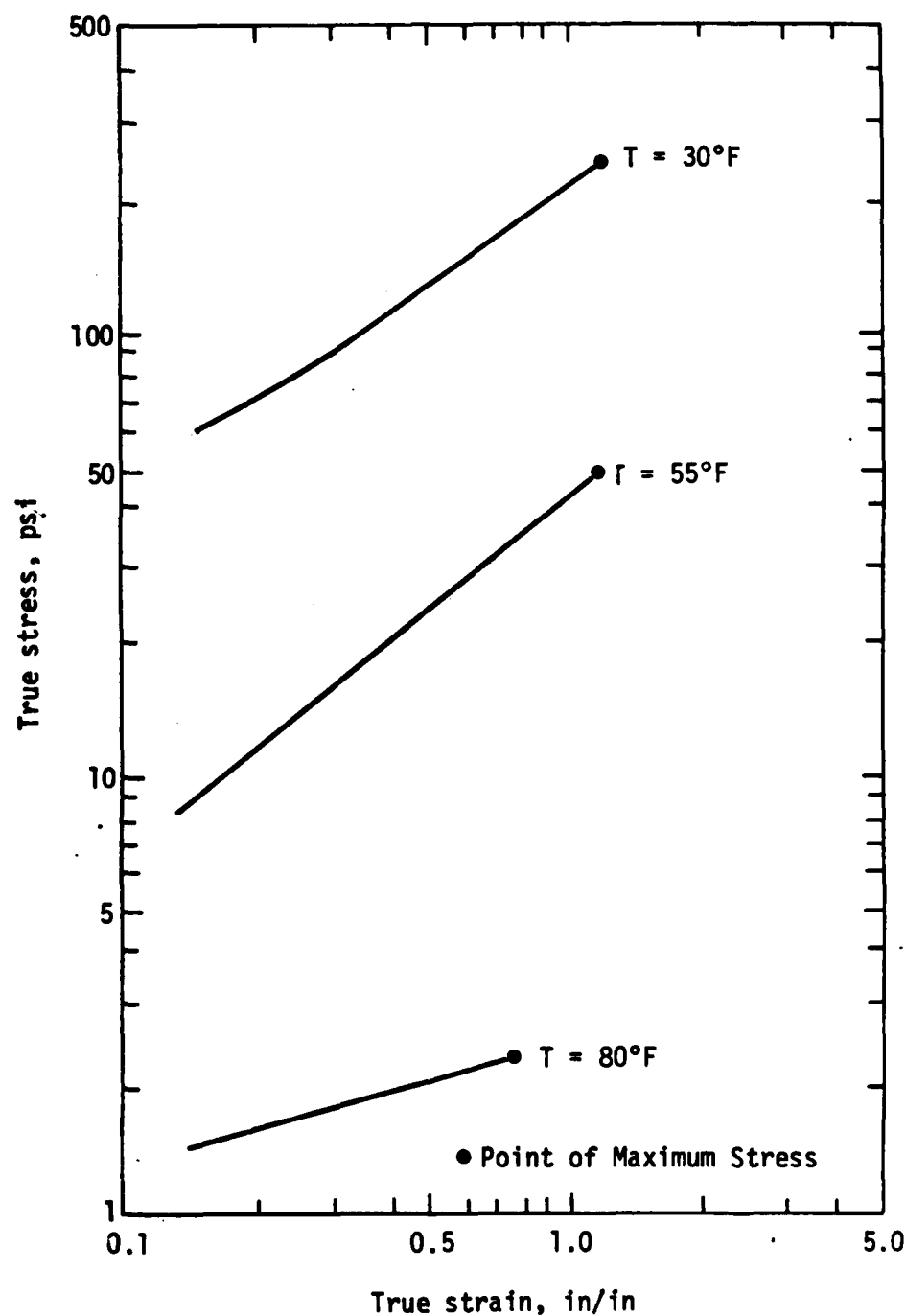


Figure C-7. Stress-Strain Curves for APC-10, AC-10 at Different Temperatures and a Deformation Rate of 0.32 in/min.

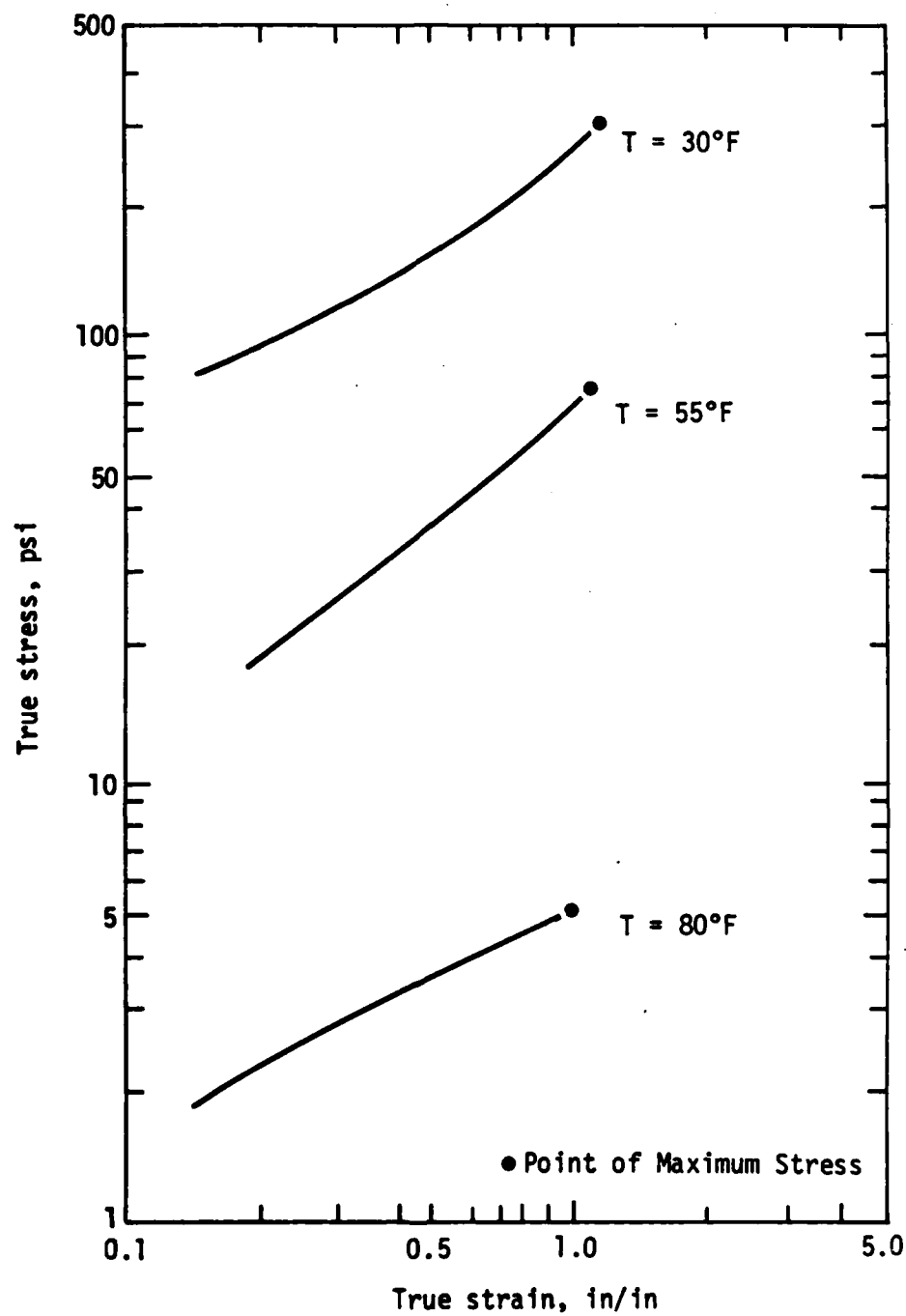


Figure C-8. Stress-Strain Curves for APC-10, AC-10 at Different Temperatures and a Deformation Rate of 0.32 in/min.

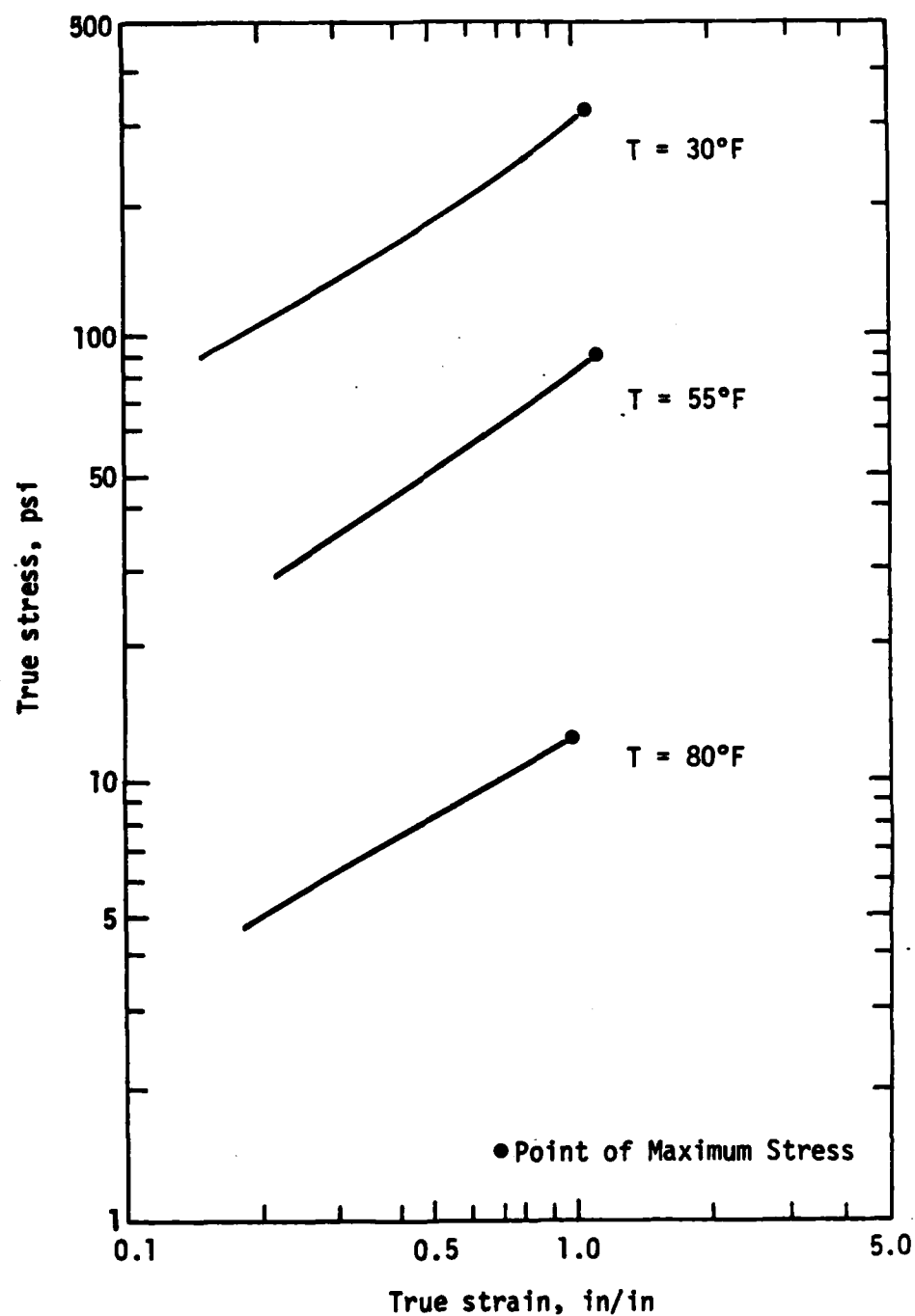


Figure C-9. Stress-Strain Curves for APC-10, AC-20 at Different Temperatures and a Deformation Rate of 0.32 in/min.

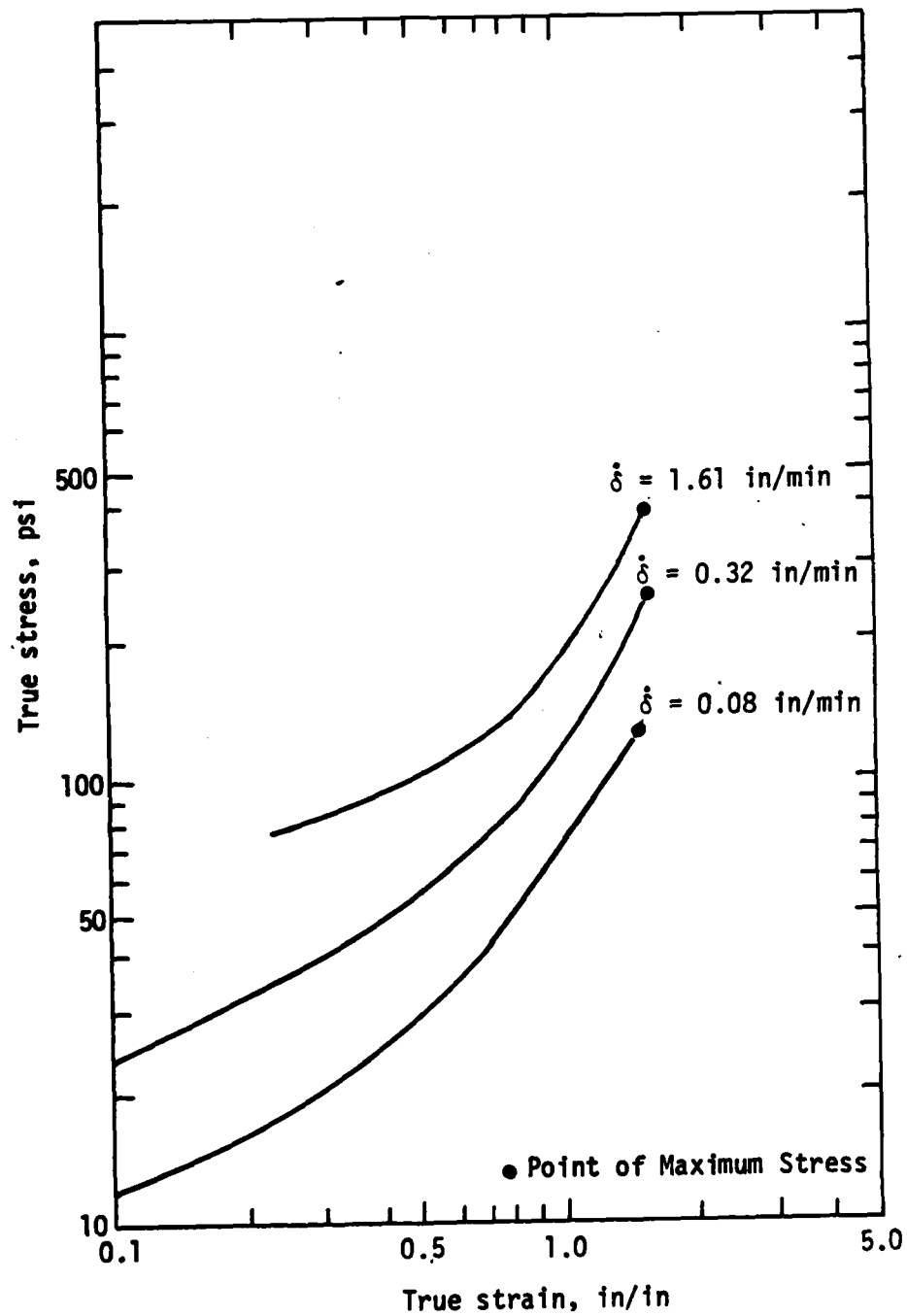


Figure C-10. Stress-Strain Curves for TP044, AC-5 at Different Deformation Rates and 39.2° F.

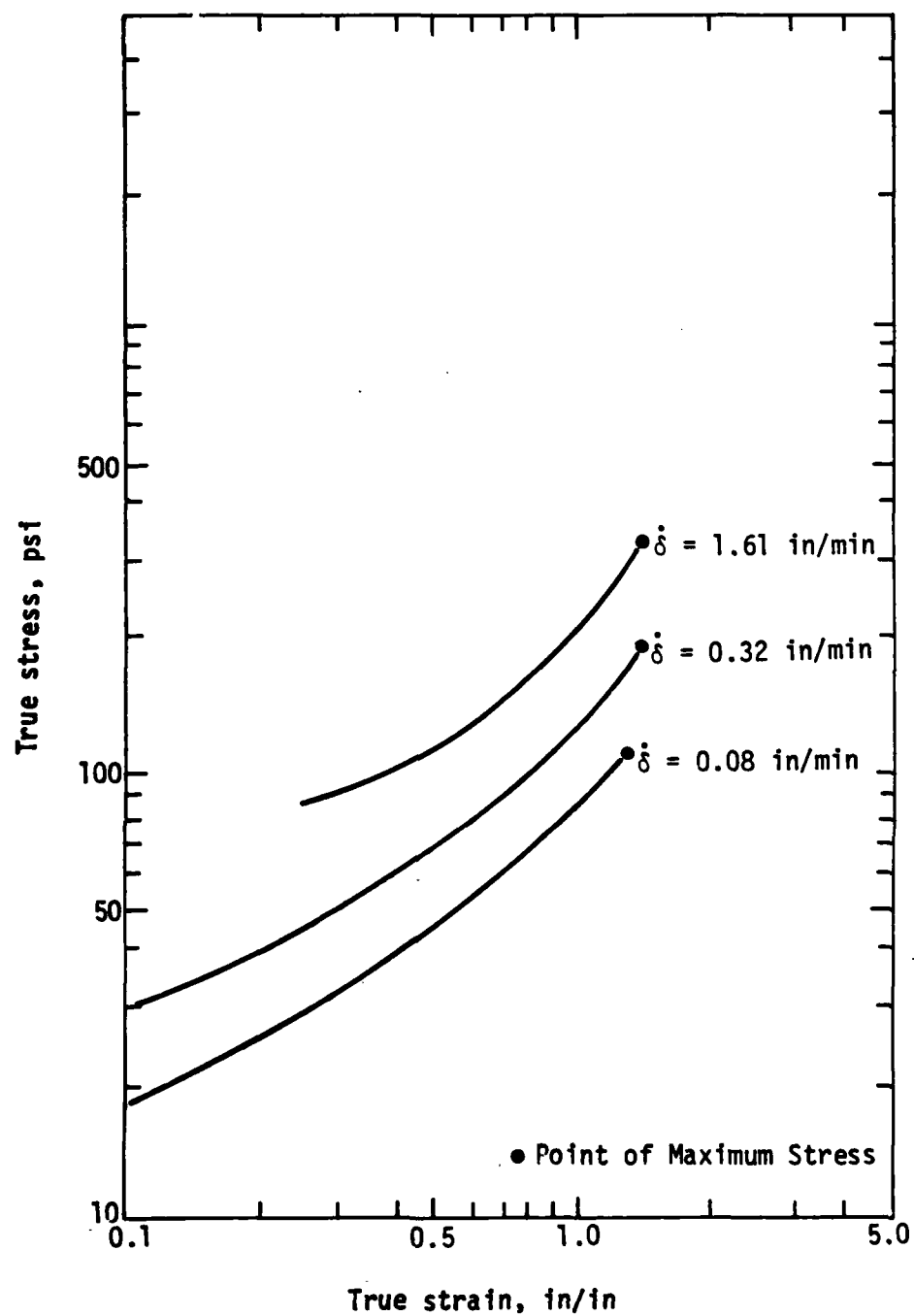


Figure C-11. Stress-Strain Curves for TP044, AC-10 at Different Deformation Rates and 39.2°F.

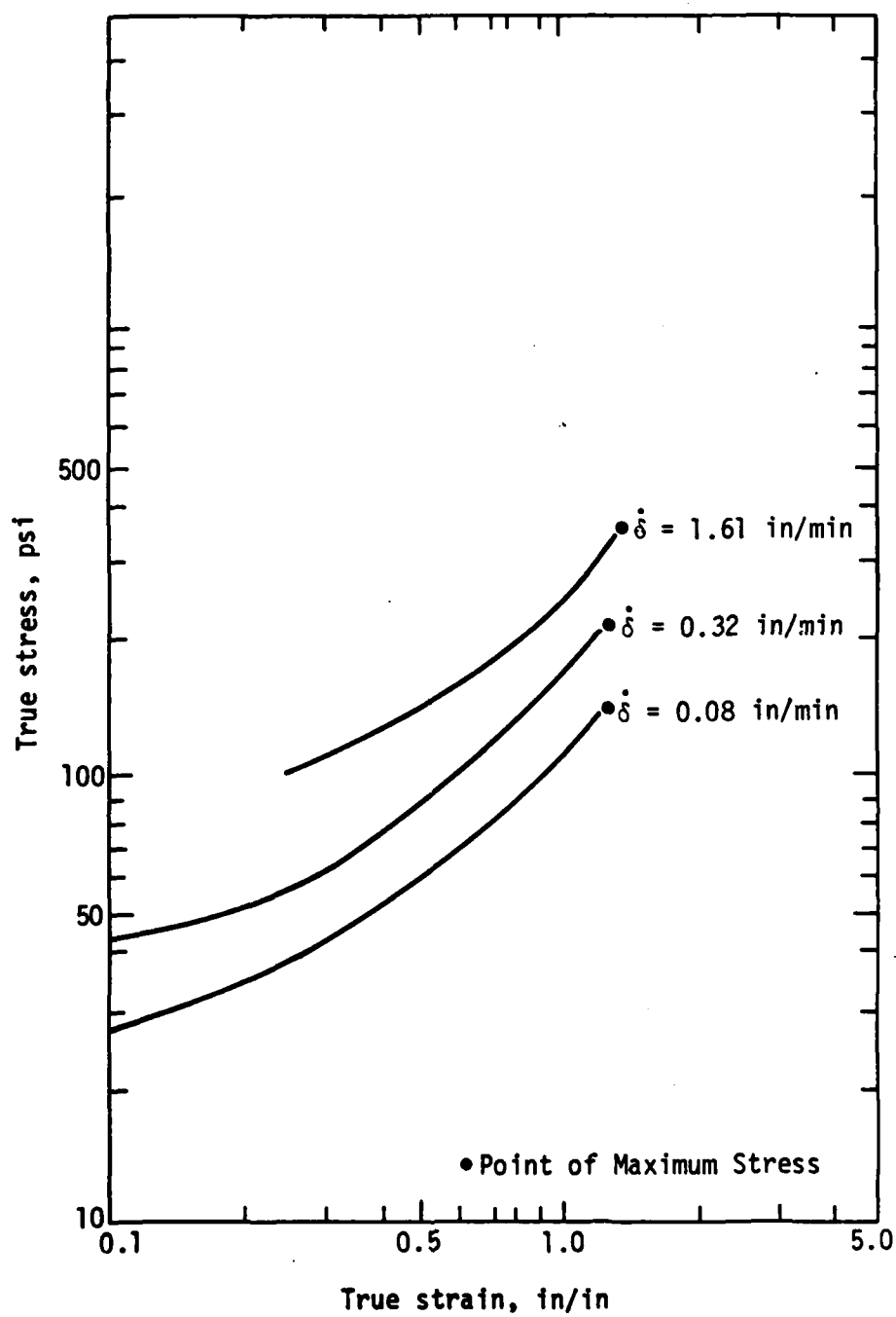


Figure C-12. Stress-Strain Curves for TP044, AC-20 at Different Deformation Rates and 39.2°F.

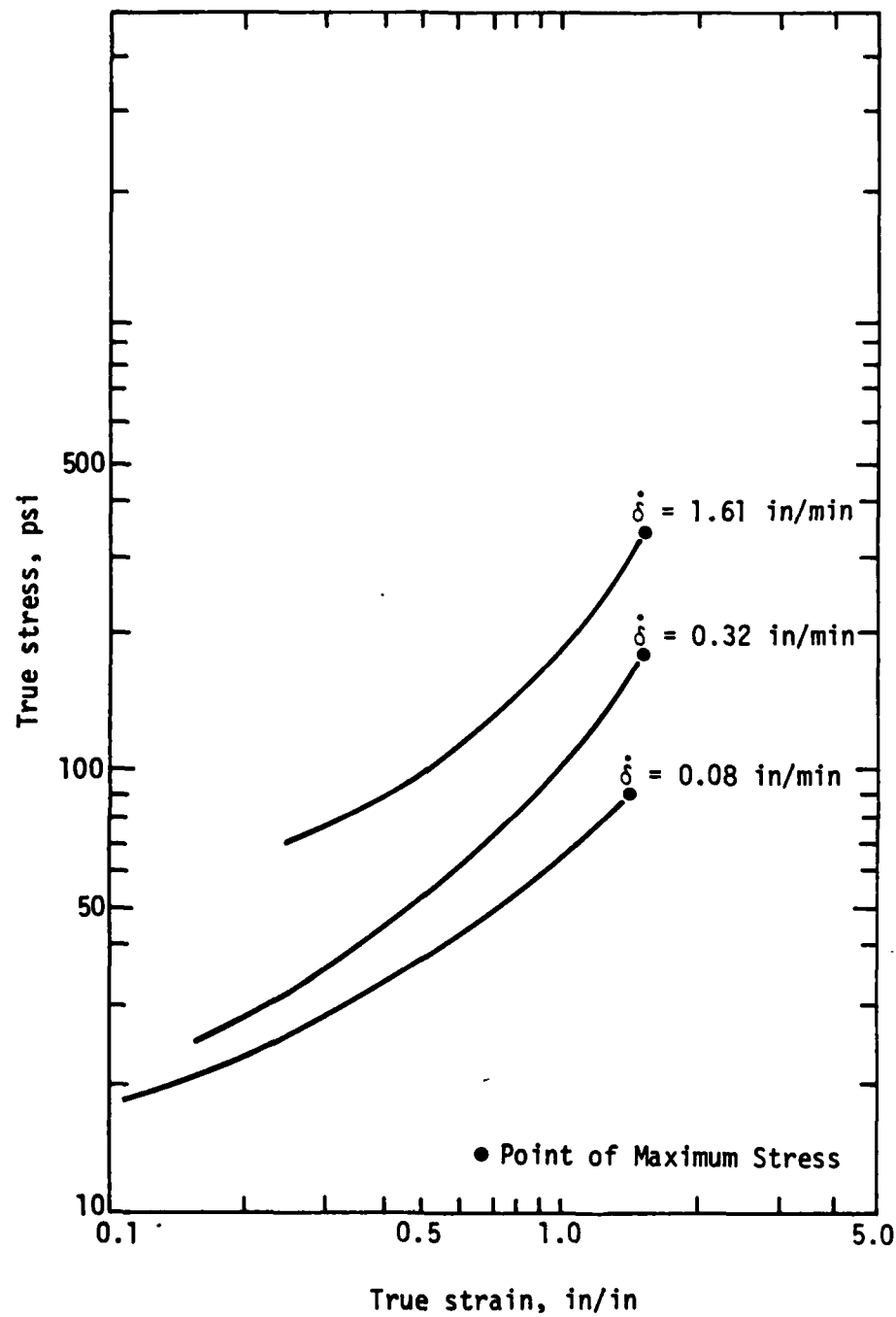


Figure C-13. Stress-Strain Curves for C-104, AC-5 at Different Deformation Rates and 39.2°F.

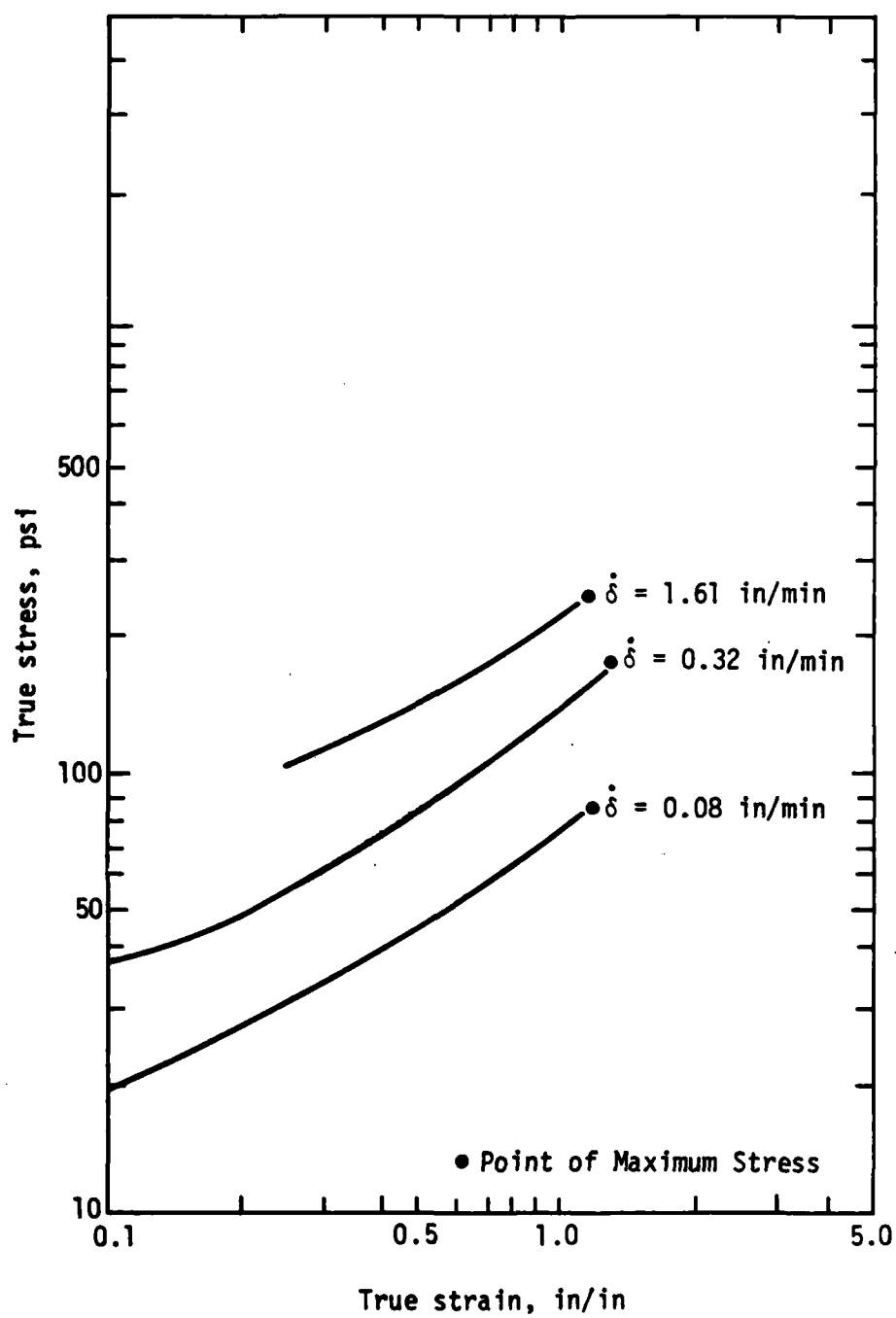


Figure C-14. Stress-Strain Curves for C-104, AC-10 at Different Deformation Rates and 39.2°F.

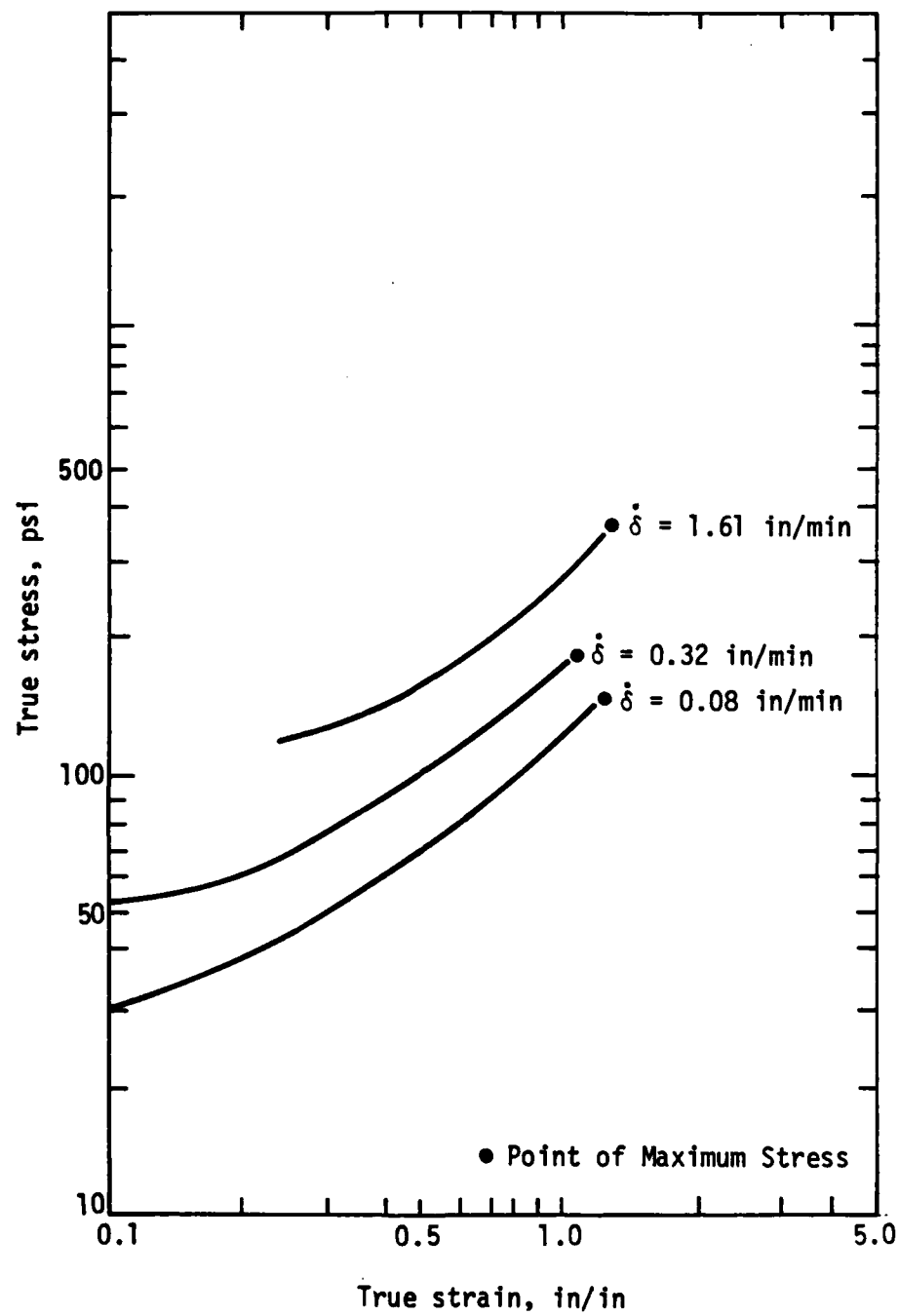


Figure C-15. Stress-Strain Curves for C-104, AC-20 at Different Deformation Rates and 39.2°F.

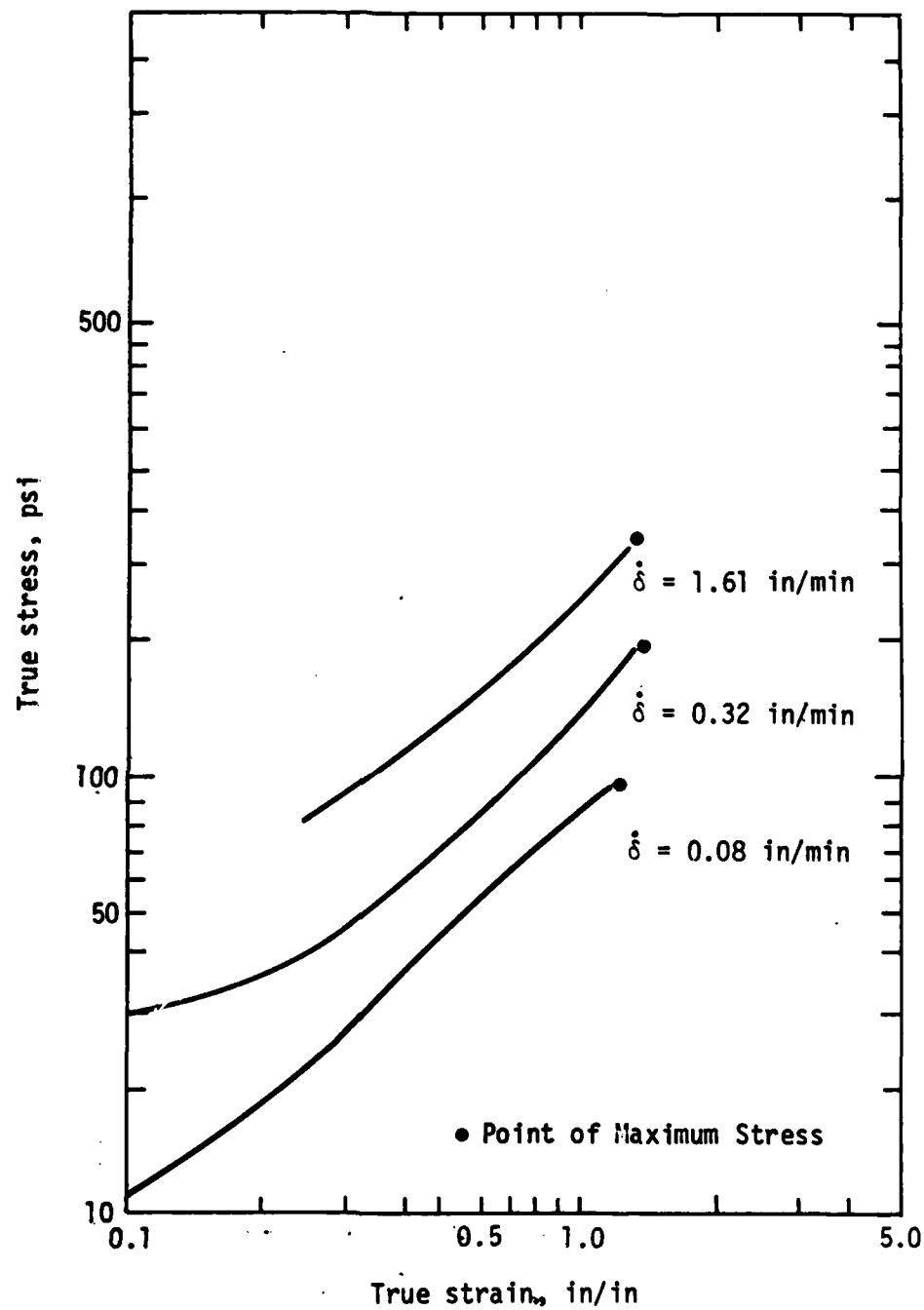


Figure C-16. Stress-Strain Curves for APC-10, AC-5 at Different Deformation Rates and 39.2°F.

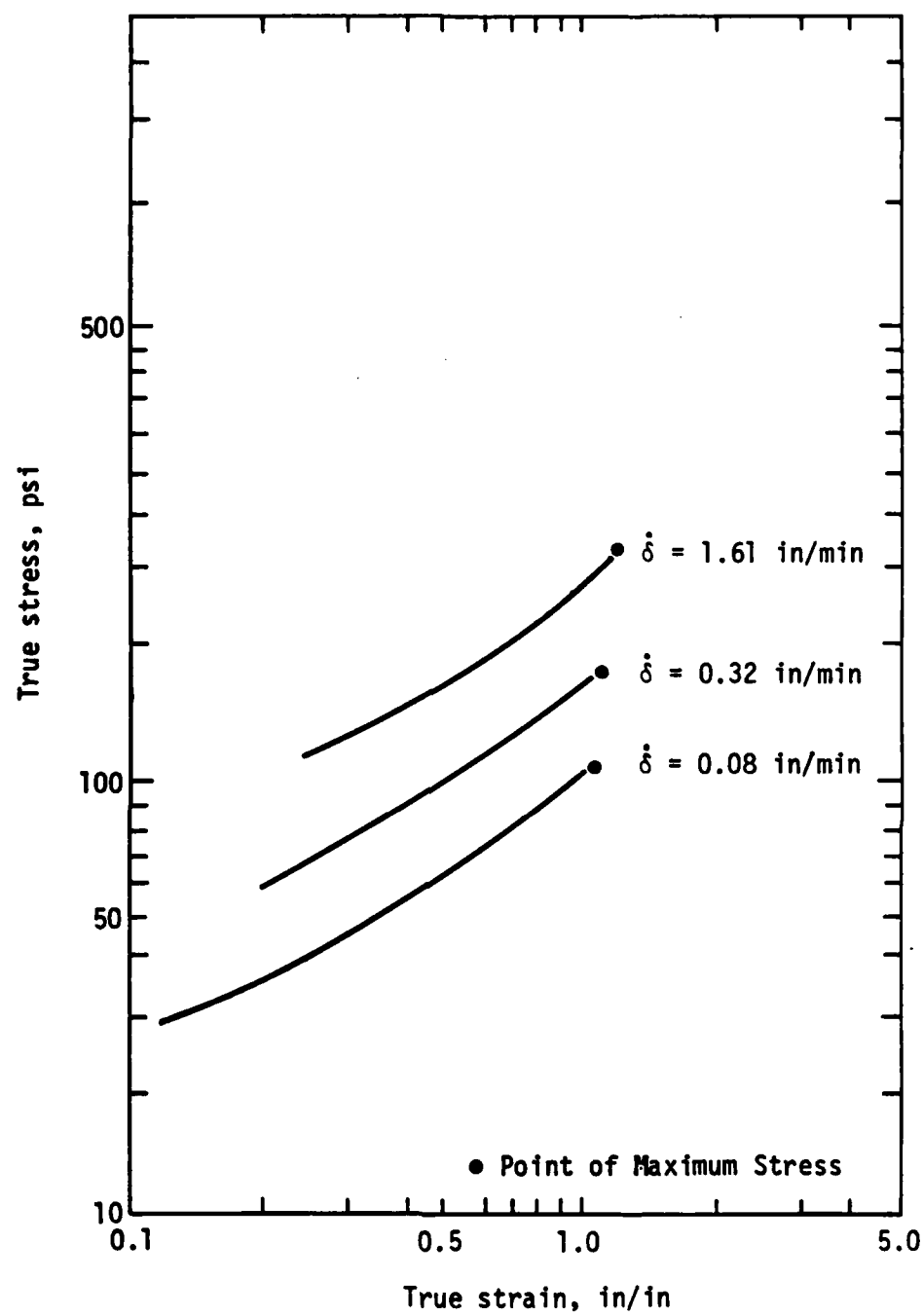


Figure C-17. Stress-Strain Curves for APC-10, AC-10 at Different Deformation Rates and 39.2°F.

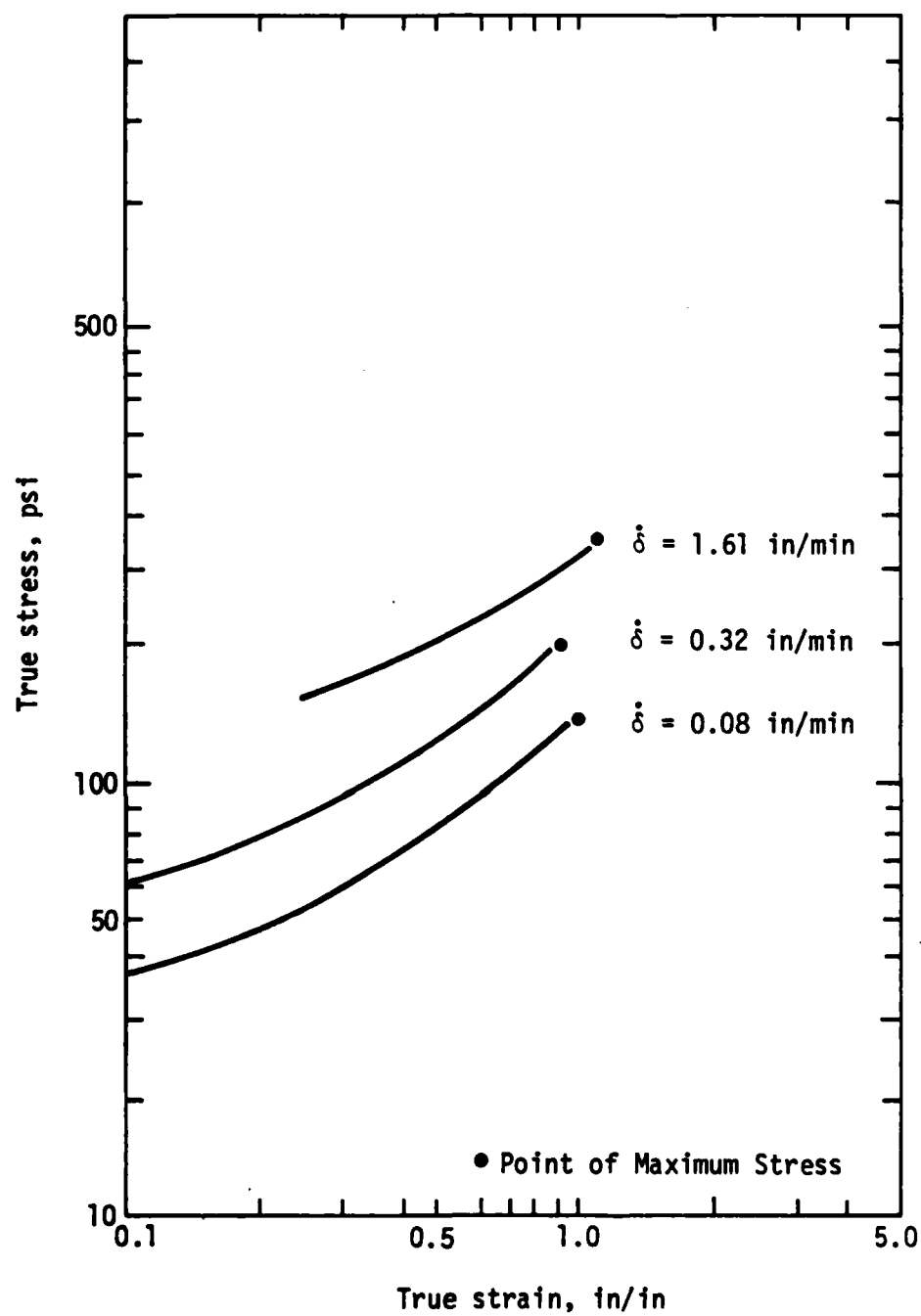


Figure C-18. Stress-Strain Curves for APC-10, AC-20 at Different Deformation Rates and 39.2°F.

APPENDIX D

CONTRACT GUIDE SPECIFICATIONS
ASPHALT-RUBBER
STRESS ABSORBING MEMBRANE INTERLAYER (SAMI)

AIR FORCE ENGINEERING AND SERVICES CENTER
CONTRACT GUIDE SPECIFICATIONS
ASPHALT-RUBBER
STRESS ABSORBING MEMBRANE INTERLAYER (SAMI)
FOR USE IN OVERLAYS OF FLEXIBLE AND RIGID PAVEMENTS

- 1.0 Applicable Publications
- 2.0 Submittals
- 3.0 Materials
- 4.0 Equipment
- 5.0 Construction
- 6.0 Tests and Field Inspections
- 7.0 Pay Items
- Attachment A--Modified Softening Point Test
- Attachment B--Notes to Design Engineer

ASPHALT-RUBBER
STRESS ABSORBING MEMBRANE INTERLAYER (SAMI)
(See Notes to Design Engineer)

1.0 APPLICABLE PUBLICATIONS. The following American Society for Testing and Materials (ASTM) publications form a part of this specification:

- E11 - 70 Specification for wire-cloth sieves for testing purposes
- D86 - 78 Distillation of petroleum products
- C88 - 76 Test for soundness of aggregates by use of sodium sulfate or magnesium sulfate
- C131 - 76 Resistance to abrasion of small-size coarse aggregate by use of the Los Angeles machine
- D946 - 74 Specification for penetration-graded asphalt cement for use in pavement construction
- D5 - 73 Cone Penetrometer Test
- D1139 - 79 Specification for crushed stone, crushed slag, and gravel for single or multiple bituminous surface treatments
- D3381 - 76 Specification for viscosity-graded asphalt cement for use in pavement construction
- D2007 - 75 Characteristic groups in rubber extender and processing oils by the Clay-Gel Adsorption Chromatographic Method

2.0 SUBMITTALS

2.1 Materials. The contractor shall furnish the following for the Contracting Officer's approval not later than 7 calendar days before membrane placement. It is imperative that the materials represented in the submittals be the same as those used in design and construction.

- 2.1.1 Asphalt manufacturer and asphalt source for mixture.
- 2.1.2 Asphalt grade for mixture.
- 2.1.3 Rubber source for mixture.
- 2.1.4 Design mixture including rubber content expressed as percent of total asphalt and rubber weights.
- 2.1.5 Asphalt, rubber, and (specify crack sealant if applicable).
- 2.1.6 Cover aggregate source, sample, gradation, and properties.
- 2.1.7 Blotter sand source, sample, and gradation.

2.1.8 Letter from diluent manufacturer certifying compliance with diluent requirements.

2.1.9 Letter from rubber manufacturer certifying compliance with rubber requirements.

2.1.10 Asphalt modifier sample or a letter from testing laboratory certifying that asphalt complies with requirements of paragraph 3.1.

2.2 Equipment. The contractor shall furnish a complete description of equipment planned for the membrane construction to the Contracting Officer for approval not later than 30 calendar days prior to commencing any work.

2.3 Quality Control Plan. The contractor shall provide a quality control plan including field personnel and procedures as well as the laboratory or laboratories which will design the mixture and conduct field and laboratory control tests. The plan shall be furnished to the Contracting Officer for approval not later than 30 calendar days prior to commencing any field work.

2.4 Contractor Experience. The contractor shall provide evidence of successful SAMI installation on at least one previous project not later than 30 calendar days prior to commencing any field work.

2.5 Delivery Tickets. Documentation showing net weight of all material placed during construction of the asphalt-rubber membrane shall be provided daily to the Contracting Officer's Representative.

3.0 MATERIALS

3.1 Asphalt. The asphalt shall be (specify appropriate viscosity or penetration) graded according to (show applicable specification). When chemical compositional analyses of the asphalt in accordance with ASTM D2007 reveal less than 20 percent aromatics, by weight of the asphalt, a modifier complying with paragraph 3.3 shall be added. The addition of this modifier shall not relieve the contractor of meeting the viscosity requirements for the asphalt.

3.2 Tack coat. (See Notes to Design Engineer.)

3.3 Asphalt Modifier. Is required if asphalt cement does not comply with aromatics content requirements of paragraph 3.1. The modifier shall have the following properties:

Flash, COC, °F (°C)	390 (199)
Aniline Point, MIXED °F (°C)	75-110 (24-43.5)
Saturates (ASTM D2007), Weight, %	20
Aromatics (ASTM D2007), Weight, %	50

3.4 Rubber. The rubber shall be granulated, reclaimed passenger (see notes to Design Engineer about type and grade) tire rubber. Not less than 80 percent by weight of rubber shall be vulcanized.

3.4.1 Gradation. Rubber shall meet the following gradations:

<u>Sieve Size</u>	<u>Percent Passing</u>
No 8	100
No 30	0-15
No 50	0-5

3.4.2 Contaminants. Rubber shall contain less than 1 percent by weight of loose fabric, wire, or other contaminants, except up to 4 percent by weight calcium carbonate or talc may be added to prevent rubber particles from sticking together. Moisture shall not exceed 1 percent by weight of the rubber.

3.5 Crack Sealant. (See Notes to Design Engineer.)

3.6 Diluent. The diluent, if used, shall have a minimum initial boiling point of 350°F and end point of 525°F when tested IAW ASTM D86.

3.7 Cover Aggregate. Shall be a washed, crushed aggregate that meets ASTM D1139, Size No. 8.

3.7.1 Aggregate gradation requirement:

<u>Sieve Size</u>	<u>Percent Passing</u>
1/2 inch	100
3/8 inch	85-100
No 4	10-30

No 8	0-10
No 16	0-5
No 200	0-1

3.7.2 Aggregate soundness. The maximum soundness loss when tested IAW ASTM C88 shall be 12 percent.

3.7.3 Abrasion resistance when tested IAW ASTM C131 shall be 40 percent or less of wear.

3.7.4 Fractured faces. Crushing shall be regulated so that not less than 60 percent by weight of aggregate retained on the No. 4 sieve shall have not less than two fractured faces.

3.8 Blotter Material. Shall be a fine aggregate (sand) conforming to the following gradation requirements:

<u>Sieve Size</u>	<u>Percent Passing</u>
3/8 inch	100
No 4	80-100
No 16	45-80
No 50	10-30
No 100	2-10

4.0 EQUIPMENT. The following equipment items are not intended to be all-inclusive, merely a description of the major equipment required to install the membrane. The contractor shall provide all equipment required to install the SAMI membrane. The Contracting Officer shall require the contractor to replace any equipment producing an unsatisfactory membrane.

4.1 Asphalt-Rubber Equipment

4.1.1 Asphalt heating tank shall utilize a uniform indirect heating system to transfer heat to the asphalt cement. A thermostatic heat control device with continuous recording graph shall monitor temperatures to assure optimum blending conditions.

4.1.2 Blender shall mechanically blend the asphalt and rubber and agitate continually until transferred to the distributor. Both asphalt totalizing meter and flow rate meter shall be provided. Batch weight percentages of all components shall be utilized and recorded at the blender. One copy of all batch weight documentation shall be given to the Contracting Officer's representative daily.

4.1.3 Distributor shall be self-powered and equipped with an indirect heating system capable of maintaining specified temperatures, agitator capable of maintaining a homogeneous asphalt-rubber mixture, pumps capable of spraying asphalt-rubber with a control variation of +0.05 gallon per square yard of the specified rate, and a fully circulating spray bar capable of applying asphalt-rubber uniformly. Sampling ports shall be located in a recirculating line to permit withdrawal of representative samples for quality control. Volume measuring devices, pressure gages, thermometer, tachometer, and spray bar nozzles shall all be in excellent working order at all times. The nozzles shall be under continuous surveillance and readily accessible for unplugging when in use.

4.2 Cover Aggregate Spreader shall be a self-propelled machine equipped with pneumatic tires and an aggregate receiving hopper in the rear. The material flow shall be carried by conveyors to a full-width distribution auger and spreader capable of spreading aggregate at a uniform rate.

4.3 Rollers to embed the aggregate shall be self-propelled and pneumatic-tired. Tire pressures shall be 100 ± 5 psi. Each tire shall carry a minimum of 4000 pounds. Maximum operating speed of the roller shall be 8 mi/h.

4.4 Power Broom shall be self-propelled and rotary type for pavement cleaning and removal of all loose aggregate from the surface of the membrane interlayer just prior to the placement of the asphalt concrete overlay.

4.5 Trucks for aggregate hauling shall be tailgate-discharge type and equipped with a device to lock onto the rear of the aggregate spreader. Trucks and aggregate spreader shall be compatible so that smooth transfer of material and uniform forward movement of the spreader occurs.

5.0 CONSTRUCTION. The contractor shall be responsible for providing all labor, materials, tools, equipment, and quality control necessary to prepare the existing pavement surface and to construct the asphalt-rubber stress-absorbing membrane interlayer.

5.1 Preparation of the Existing Pavement Surface. (See Notes to Design Engineer.)

5.2 Tack Coat. (See Notes to Design Engineer.)

5.3 Mixing. The asphalt and rubber shall be combined and mixed in a blender unit and reacted in a distributor for a period of time to be determined by laboratory testing by the supplier. In no case shall the criteria of paragraph 5.3.4 be exceeded.

5.3.1 Proportion of the rubber shall be 23 ± 4 weight percent of total mixture comprised of asphalt cement, asphalt modifier (if used), and granulated rubber.

5.3.2 Asphalt temperature at time of rubber addition shall not exceed 425°F nor fall below 375°F.

5.3.3 Mix times

5.3.3.1 Rubber addition to the hot asphalt shall be accomplished in not more than one 30-minute time span.

5.3.3.2 Temperature stabilization period. The mixture shall attain a stable temperature between 325°F and 340°F within 60 minutes following initiation of rubber addition, and the temperature shall not be allowed to deviate from this range after stabilization.

5.3.3.3 Asphalt-Rubber reaction period of not less than 60 nor more than 90 minutes following initial rubber addition shall be allowed for the asphalt-rubber mixture to react before adding any diluent or distribution the mixture. Laboratory testing shall be used to further define the reaction period.

5.3.3.4 Application of the mixture shall be completed within 2 hours following initial rubber addition.

5.3.4. Diluent not in excess of 7.5 percent by volume of the hot asphalt-rubber mixture may be used to adjust the viscosity for more uniform coverage. Diluent shall not be added to the mixture until after the asphalt-rubber action has occurred.

5.3.4.1 Additional diluent not exceeding 3 percent by volume of the hot asphalt-rubber mixture may be added after reheating a mixture which has been cooled by job delay. Reheating shall occur slowly and temperature of the mixture shall not exceed 325°F.

5.3.4.2 Caution. The temperature of the asphalt-rubber shall not exceed 340°F at time of diluent addition. The contractor is reminded that the flash point of the diluent is probably below the normal operating temperatures used in this process and that the contractor shall observe proper precautions for protection of life and property.

5.4 Application of Asphalt-Rubber Material

5.4.1 Restrictions. Placement of asphalt-rubber material shall be made only under the following conditions:

5.4.1.1 Temperature. The ambient temperature is not less than 65°F and rising.

5.4.1.2 Precipitation is not expected within the period of application and the pavement surface is clean and absolutely dry.

5.4.1.3 Wind velocity is low enough to preclude blowing of the spray bar fans.

5.4.1.4 Equipment is all in position and ready to commence placement.

5.4.1.5 Contracting Officer's Representative is present and has authorized commencement.

5.4.2 Application rate shall be a nominal 0.55 gallons per square yard (based on 7.5 pounds per hot gallon).

5.4.2.1 The contractor shall determine the surface demand and submit resulting application rate for the Contracting Officer's approval. Contract payment shall be decreased or increased in accordance with the actual quantity of mixture used and the contractor's unit price for the mixture.

5.4.2.2 If visual appraisal of application reveals lean or fat areas, these shall be remedied by application of additional asphalt-rubber or of sand blotter at the unit price contracted. See paragraph 5.5.4 for placement of blotter material.

5.4.3 Joints. All longitudinal joints shall be overlapped a minimum of 4 inches. Transverse joints shall be constructed by placing building paper across and over the end of the previous asphalt-rubber application and starting the extension on the paper. When the distributor has cleared the paper, the latter shall be immediately removed.

5.5 Cover Aggregate

5.5.1 Rate of application of aggregate shall be a nominal 35 pounds per square yard. The contractor shall change this rate only if visual inspection indicates the need or if tracking of the binder occurs and, in either case, approval has been obtained from the Contracting Officer's Representative.

5.5.2 Aggregate Spreader shall follow the distributor as closely as practicable and never lag more than 150 feet.

5.5.3 Joints. Aggregate shall only be applied to the asphalt-rubber in the area of the longitudinal joint lap after the second, overlapping application of asphalt-rubber. This is to prevent a double layer of aggregate and subsequent thinning of the overlay.

5.5.4 Rolling. Sufficient, but in no case less than three, pneumatic-tired rollers shall be employed to:

5.5.4.1 Follow immediately behind the spreader.

5.5.4.2 Complete one pass, full width within 90 seconds after spreading.

5.5.4.3 Complete four passes, full width within 1 hour after asphalt-rubber application.

5.5.5 Removal of loose material with the rotary power broom shall follow the rollers. The initial sweeping shall be a light brooming at the end of the placement day. Heavier brooming, sufficient to remove all loose cover aggregate, shall commence no earlier than the day following membrane placement. The heavy brooming shall be delayed if dislodgment of aggregate occurs. Prior to placement of the overlay, a final sweeping shall be accomplished to remove any vestiges of loose material. Sweepings shall be disposed by the contractor as specified in the special provisions of this contract.

5.5.6 Blotter material shall be applied immediately after the initial pass of the rollers if bleeding or pickup of aggregate by construction traffic is occurring. Application rate of 5 pounds per square yard shall be adjusted by trial and placed only in areas indicating need by the aforementioned.

5.6 Traffic on Membrane shall not be permitted within 3 hours following final rolling to allow time for set. Thereafter only light construction traffic shall be allowed until overlay placement. This light traffic shall not exceed 15 mi/h velocity.

5.7 Overlay. Placement of the asphalt concrete overlay shall be delayed not less than 48 hours following final rolling to allow sufficient time for adequate setting of the membrane.

6.0 TESTS AND FIELD INSPECTIONS. The criteria specified in this paragraph are offered as a guide for SAMI construction. (See Notes to Design Engineer.)

6.1 The modified softening point temperature of the asphalt-rubber mixture when tested IAW Attachment A will be a minimum of 110°F.

6.2 The penetration of the asphalt-rubber mixture when tested IAW ASTM D-1191 (Cone Penetrometer) at 77°F, 150 g, 5 s, will be a minimum of 70.

7.0 PAY ITEMS

7.1 The Contract Price shall be lump sum and equal the total square yards of SAMI surface times the unit price per square yard.

7.2 Adjustments. If job conditions and Contracting Officer mandate a change from the nominal quantities specified herein, the contract amount shall be decreased or increased according to the following:

7.2.1 The asphalt-rubber shall be measured and paid for by ton of mixture in place and includes all material used in the mixture.

7.2.2 The cover aggregate shall be measured and paid for by ton of cover aggregate in place.

7.2.3 The blotter material shall be measured and paid for by ton of blotter sand in place.

ATTACHMENT A
ASPHALT-RUBBER (SAMI) SPECIFICATION
MODIFIED SOFTENING POINT TEST

1.0 SCOPE. This method covers the determination of the softening point of asphalt-rubber materials using a modified apparatus in an ethylene glycol bath.

2.0 SUMMARY OF METHOD. A cylindrical sample of asphalt-rubber is molded between two steel balls of specified weight and diameter. One of the steel balls is attached to a magnet in an ethylene glycol bath so that the sample is vertical. The bath is heated at a uniform prescribed rate and the softening point taken as the temperature at which the bottom ball, attached to the sample, falls a distance of 1 inch.

3.0 SIGNIFICANCE

3.1 The ring-and-ball softening point temperature is a useful method in classifying bituminous materials. However, for asphalt-rubber it has been noted that there is a tendency for the ball to fall through the material prior to the end of the test. Therefore the modified softening point test was developed to improve the repeatability of the test.

3.2 The modified softening point is a useful means of defining asphalt-rubber flow properties.

4.0 APPARATUS

4.1 Mold. A two-piece brass mold conforming to the dimension shown in Figure D-1.

4.2 Balls. Steel balls 3/8 inch in diameter each weighing 3.50 ± 0.05 grams.

4.3 Bath. A 1000 ml low-form Griffin beaker of heat resistant glass or its equivalent.

4.4 Glass Tube. A 9 mm glass tubing approximately 6 inches long.

All dimensions are in inches.

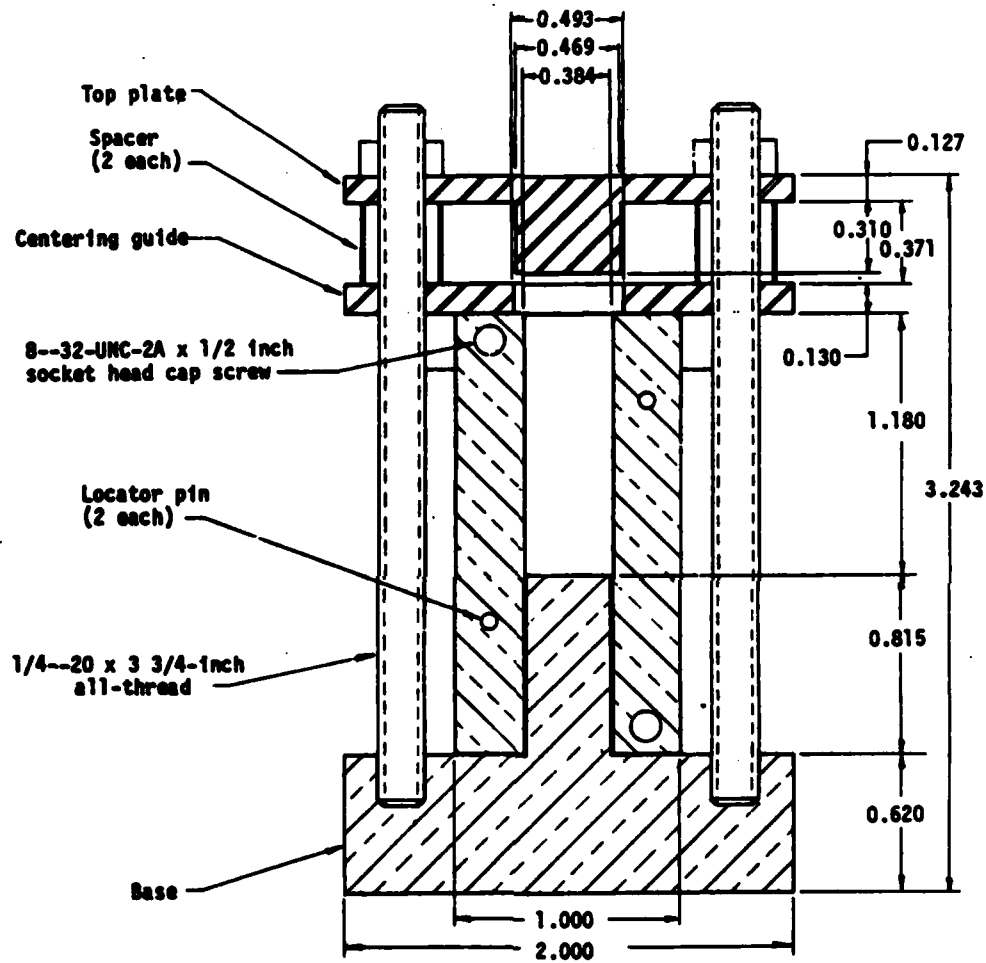


Figure D-1. Modified Softening Point Sample Mold.

4.5 Wooden Dowel. Approximately 6 inches long and having a diameter of 1/4 inch.

4.6 Rubber Bulb. One- to two-ounce capacity with a 1/4 inch opening.

4.7 Sample Holder. An assembly conforming to the materials and dimensions shown in Figure D-2.

4.8 Thermometer. Conforming to the Thermometer 113°F or 113°C as specified in ASTM E1.

5.0 REAGENTS AND MATERIALS

5.1 Bath Liquid. Ethylene glycol with a boiling point between 383°F and 387°F.

CAUTION: Ethylene glycol is toxic when taken internally or when inhaled as a vapor. Conduct the test in a hood or other well-ventilated location. Avoid prolonged or repeated contacts with skin and inhalation of vapors.

6.0 PREPARATION OF SAMPLE

6.1 Heat the sample with care, stirring constantly to prevent local overheating, until the sample has become sufficiently fluid to pour. In no case should the temperature be raised to more than 325°F. Do not heat for more than 60 minutes.

6.2 Line the assembled mold with one thickness of nonstick paper.

6.3 Place the squeeze bulb over one end of the glass tube and gently heat the glass tube over a flame.

NOTE: Steps 6.3 through 6.6 must be completed in less than 60 seconds to keep the asphalt-rubber in a workable state.

6.4 Insert the glass tube into the sample and withdraw a sufficient amount of asphalt-rubber to fill the mold.

6.5 Place a heated ball into the mold. Remove the squeeze bulb from the end of the glass rod and force the sample into the tube with the wooden dowel.

All dimensions are in inches.

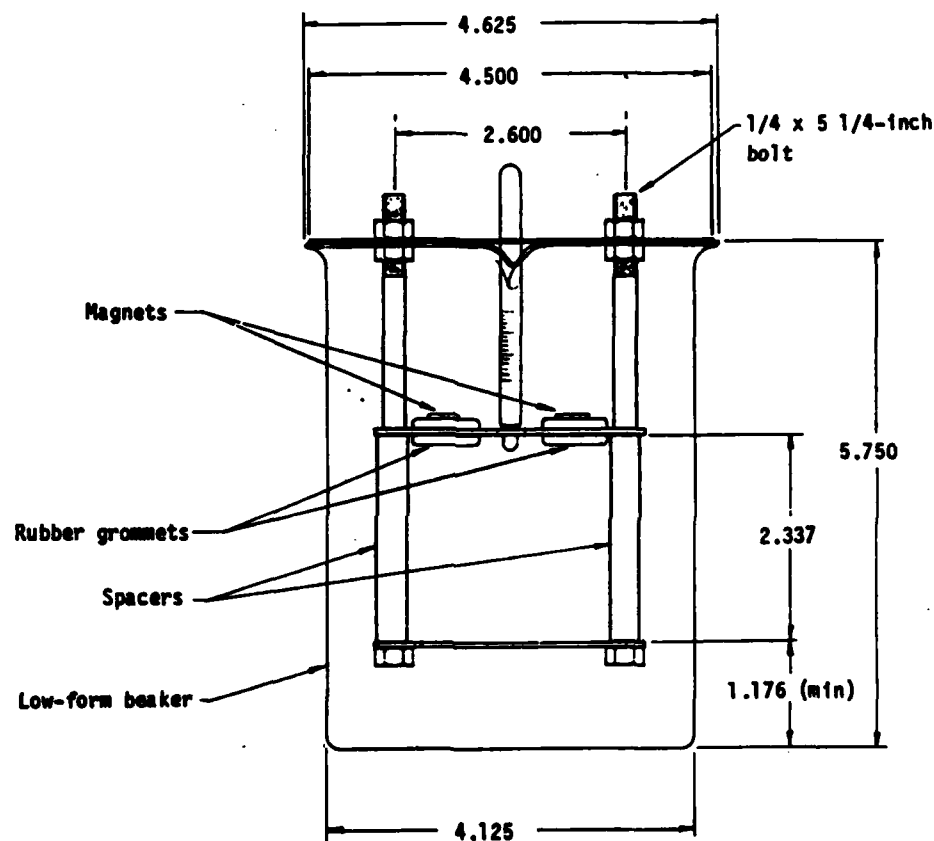


Figure D-2. Modified Softening Point Testing Apparatus.

6.6 Place the other heated ball on top of the molded sample and place the top plate on the mold assembly, tightening the nuts.

6.7 Allow the sample to cool for 5 minutes in the mold. Disassemble the mold and remove the sample. Tape and freeze the sample for 30 minutes. Trim excess material around the balls with a razor blade and remove the nonstick paper.

6.8 Place the sample in a 40°F ethylene glycol bath.

6.9 Repeat steps 6.1 through 6.8 for the second sample. Not more than 240 minutes should elapse between the time of pouring the first specimen and the completion of the test.

7.0 PROCEDURE

7.1 In the laboratory hood, assemble the fluid-filled apparatus with the samples suspended vertically from the magnets. Make sure that the hood exhaust fan is on and operating properly to remove toxic ethylene glycol vapors.

7.2 Heat the bath from below so that the temperature rises at a uniform rate of $9 \pm 1.0^\circ\text{F}$ per minute. Avoid drafts, using shields if necessary.

7.3 Do not average the rate of temperature rise over the test period. Reject any determination in which the rate of temperature rise does not fall within the specified limits after the first 3 minutes.

7.4 Record, for each sample, the temperature shown by the thermometer at the instant the bottom ball, attached to the sample, touches the bottom plate. Make no corrections for the emergent stem of the thermometer. If the difference between values in the duplicate determination exceeds 5°F , repeat the test.

8.0 REPORT. Report (to the nearest 1.0°F) the mean of the temperature recorded in the duplicate determination to be the modified softening point.

9.0 PRECISION. Duplicate modified softening points by the same operator should be considered suspect if they differ by more than 10°F. This is based upon 95 percent probability.

ATTACHMENT B
ASPHALT-RUBBER
(SAMI)
NOTES TO DESIGN ENGINEER

GENERAL

Stress absorbing membrane interlayers are intended to retard reflection cracking in asphalt concrete overlays placed on rigid and flexible pavements. Stress due to thermal expansion and contraction in pavements increases with increasing crack spacing and increased thermal cycling. Therefore the more severe the climate the smaller the acceptable crack spacing. These parameters are not sufficiently defined at the present time to quantify them. However, the engineer should be aware that if this amount of thermal cycling and crack spacing is great enough, interlayer systems may be of marginal value.

This specification is for one type of asphalt-rubber product using vulcanized, ground tire rubber. Another asphalt-rubber product is available using devulcanized tire rubber. Another specification should be used if the devulcanized asphalt-rubber product is to be used in construction.

Some Air Force pavement engineers have noted shoving problems in areas of high turning. It is believed that these problems were due to application of excess aggregate on the SAMI in these areas.

3.2 Tack Coat

A tack coat of asphalt emulsion or asphalt cement is required on pavement surfaces which have had only crack filling, heater scarification, or cold milling. This paragraph should read:

Tack coat shall be grade (specify appropriate emulsion or asphalt) which shall comply with the requirements of (show applicable specifications).

In cases where heater scarification is used, a rejuvenator may be specified in lieu of the tack coat. Include the applicable specification in paragraph 1.0.

3.4 Rubber

Until standard specifications for sampling and testing granulated rubber have been established, the Contracting Officer should accept a certificate of compliance from the rubber supplier stating that the rubber to be used meets the criteria listed in the specifications.

3.5 Crack Sealant

A crack sealant should be used in cases where a thin overlay or crack filling treatment is to precede the SAMI application. Do not use crack sealants with heater scarification or heater planing treatments.

The engineer should refer to Air Force Manual 88-6, Chapter 7, to select the appropriate crack sealant. This paragraph should read:

The crack sealant shall comply with Federal specification (specify appropriate specification--SS-5-1401, -1614 or -200d).

5.1 Preparation

SAMI applications may be placed on a variety of pavement surface treatments. The most effective treatments are those which remove the membrane from direct contact with existing pavement cracks by approximately 0.75 inches. These treatments include heater scarification, heater planing, and thin overlays. These methods will reduce the energy in crack tips before they reach the membrane, thus ensuring a better chance of success. Patching and crack filling of the existing pavement should precede the thin overlay treatment.

It may be more economical to patch potholes, fill cracks, and apply a tack coat on the existing surface prior to SAMI construction. The economy of this would depend upon the level of surface deterioration.

For Portland cement concrete pavements the cracks and joints should be cleaned and sealed. Potholes should be filled with compacted asphalt concrete. It is strongly recommended that a thin asphalt concrete overlay be placed on the existing pavement before the SAMI application.

Thorough sweeping of the prepared surface should be accomplished immediately prior to SAMI construction on any treatments which do not involve tack coats. The engineer should refer to the appropriate guide specifications for any of the surface treatments mentioned in this section.

5.2 Tack Coat

The design engineer may omit this requirement if a thin overlay is to be utilized prior to the SAMI application. If a tack coat is to be used in the construction, this paragraph should read:

A tack coat shall be applied with materials designated in paragraph 3.2 after thorough sweeping of the surface. Close control of application shall be required to achieve a residual asphalt rate of 0.03 to 0.05 gallons per square yard. Diluted materials shall be applied at a rate adjusted to achieve this coverage.

5.3.4.2 Caution

This paragraph is added to emphasize that precautions should be taken by the Contractor, as in working with a potentially explosive jet fuel, to guard against possible fire or explosion due to exposure of the diluent to open flames or sparks. The internal heaters and the engine of the distributor will of necessity be in operation during diluent addition. The designs should specify appropriate operating procedures found in the applicable Air Force regulation.

5.7 Overlay

If heavy traffic on the SAMI cannot be avoided prior to the placement of the overlay, the engineer is advised to place a tack coat on the SAMI to aid chip retention. This may also be achieved by using precoated aggregate.

6.0 TESTS AND FIELD INSPECTIONS

The criteria listed in this section have been verified in a limited number of construction sections. More field testing is being planned and other tests are being considered prior to implementing mandatory limits. The tests offered in paragraphs 6.1 and 6.2 require the laboratory be located on or local to the job site.

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